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An Ecological Foundation For Management of National Forest Giant Sequoia Ecosystems

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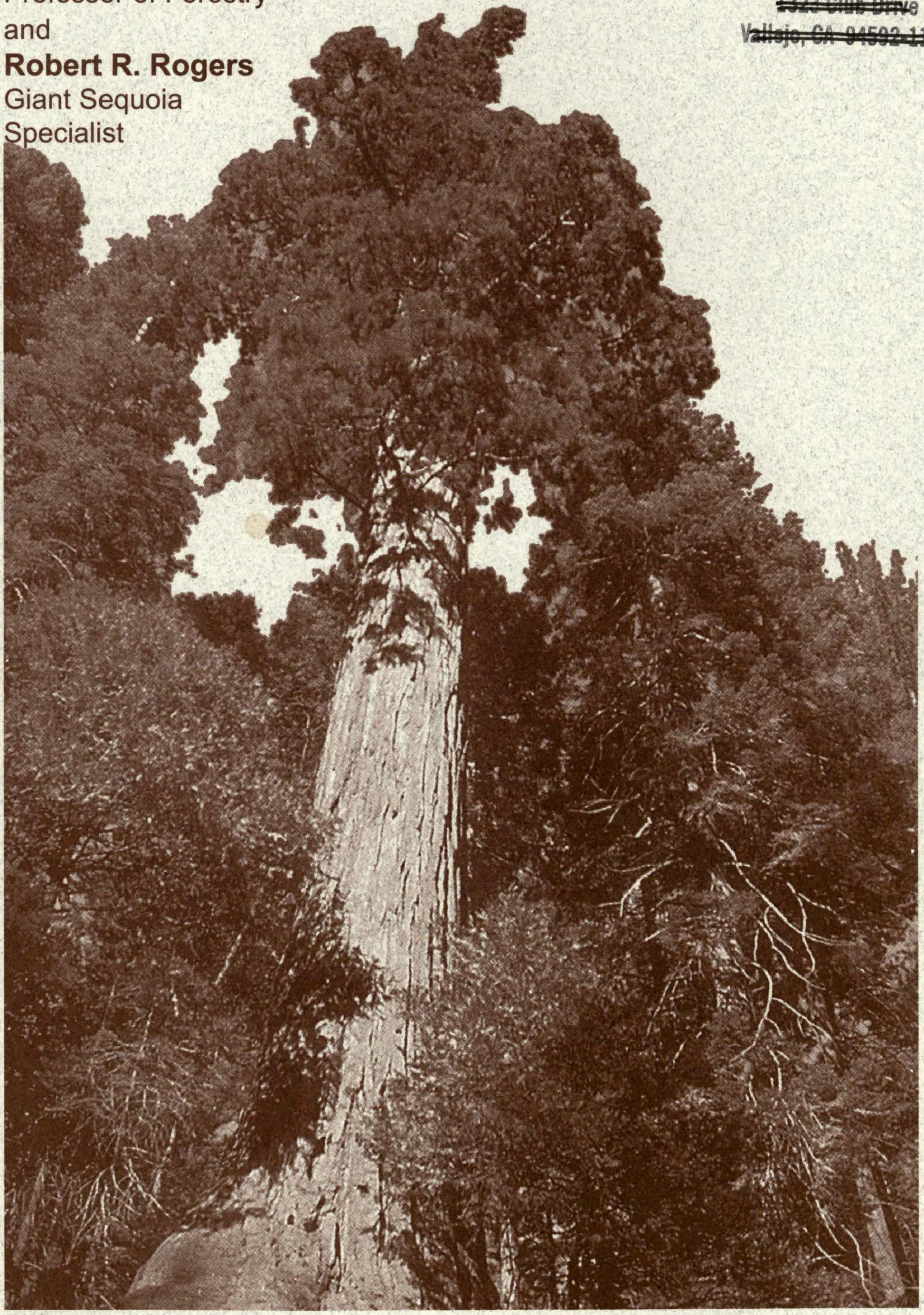

United States Department of Agriculture

Forest Service

Pacific Southwest Region
Sequoia National Forest

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Date: September 8, 1999

Dear Managers and Friends of Giant Sequoia:

The report you are about to read titled "An Ecological Foundation for Management of National Forest Giant Sequoia Ecosystems" was prepared by Dr. Douglas D. Piirto, Professor of Forestry at California Polytechnic State University, and Mr. Robert Rogers, Giant Sequoia Specialist with the USDA Forest Service, Sequoia National Forest. The Forest Service requested and provided funding for Dr. Piirto to develop this report with Mr. Rogers as part of a collaborative sabbatical leave assignment in the 1997/98 academic year.

This report responds to recommendations made in the 1990 Mediated Settlement Agreement, 1992 Presidential Proclamation, 1996 Giant Sequoia Cooperative MOU, and 1996 Sierra Nevada Ecosystem Project (SNEP) report regarding a long-term management, planning, and sustainability analysis for national forest giant sequoia groves. This analysis was conducted using the Forest Service ecosystem management process (Manley et al 1995). The results of that analysis are documented in this report.

Dr. Piirto and Mr. Rogers have established a foundation upon which we can proceed with further management planning for national forest giant sequoia groves. We seek and encourage interested parties to work with us as we continue to move towards the development of management plans for national forest giant sequoia groves. If you have any questions or comments, please send them to: Giant Sequoia Program Manager, Sequoia National Forest, 900 West Grand Avenue, Porterville, California 93257-2035.

Sincerely,

Arthur L Gaffrey

ARTHUR L. GAFFREY

Forest Supervisor

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An Ecological Foundation for Management of National Forest Giant Sequoia Ecosystems

by

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Giant Sequoia Specialist

Abstract: A strategy for the protection, preservation, and restoration of national forest giant sequoia groves is being formulated using a conceptual framework for ecosystem management recently developed by Region Five of the USDA Forest Service. The framework includes physical, biological, and social dimensions. The array of ecosystem elements and their associated environmental indicators within each of these dimensions is almost endless. Key ecosystem elements, environmental indicators, and reference variability are discussed in this paper. These key elements and associated indicators are thought to be adequate to define and control management activities designed to protect, preserve, and restore national forest giant sequoia groves for the benefit of present and future generations. The key ecosystem elements selected for practical application are: 1) attitudes, beliefs, and values; 2) economics and subsistence; 3) stream channel morphology; 4) sediment; 5) water; 6) fire; 7) organic debris; and 8) vegetation mosaic. Recommendations are made for the attributes of environmental indicators that characterize these elements.

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Giant Sequoia Management in the USDA Forest Service

INTRODUCTION

Since their discovery by settlers in 1852, giant sequoia trees (*Sequoia gigantea* [Lindl.] Decne.)[3] have fascinated people throughout the world (Figure 1a, b). Early exploitation by commercial interests led to many laws and administrative decisions designed to protect the groves where these magnificent wonders of nature are found (Piirto, Rogers, and Bethke 1997, and Tweed 1994).

Figure 1a
The Confederate Group of giant sequoias in Mariposa Grove, Yosemite National Park. Note the signs that give each large tree an individual name. *(Photo taken circa 1890).*

Figure 1b
By 1970, in the absence of frequent surface fires, a dense thicket of white firs grew at the base of the sequoias. Such thickets provide fuel that could conduct fire high into the sequoias. *(Photographs courtesy of Bruce M. Kilgore, National Park Service.)*

At first the groves were simply withdrawn from the public lands and placed in Forest Reserves or National Parks. This protected the big trees from being made into grape stakes and exhibition displays (Figure 2), but did not necessarily assure preservation of the groves over the long term. In the 1960's the National Park Service began using prescribed fire to reduce fuels in and around the giant sequoia groves. This added another dimension to the theme of protection, and also had a positive effect on long-term preservation.

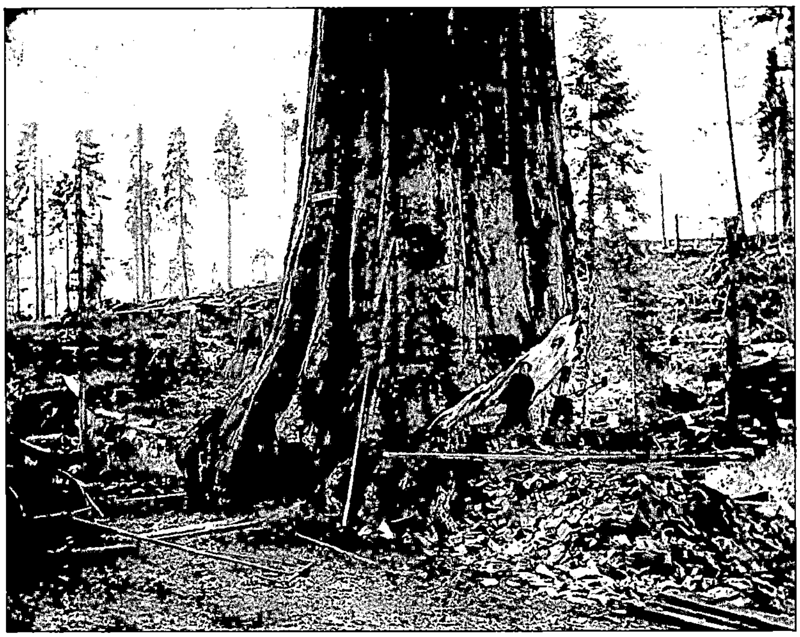

Figure 2
The Mark Twain tree stood on privately owned land when it was cut in 1891 for museum exhibition purposes. The logged over area now known as the Big Stump grove is jointly administered by the USDA Forest Service and the USDI National Park Service *(USDA Forest Service photograph).*

In 1990 the Sequoia National Forest was party to a mediated settlement agreement (USDA 1990) which established goals for giant sequoia management: to protect, preserve, and restore the groves for the benefit of present and future generations. In 1992 President Bush issued a proclamation that indirectly validated these goals and made them national in scope. Of the approximately 75 naturally occurring giant sequoia groves (Figure 3), 43 are found on national forests; most of the remainder are found in national parks (Rundel 1972a, Willard 1995, Rogers 1998). Portions of nine groves are in private ownership. All of the naturally occurring giant sequoia groves are found on the west slope of the Sierra Nevada mountains in California.

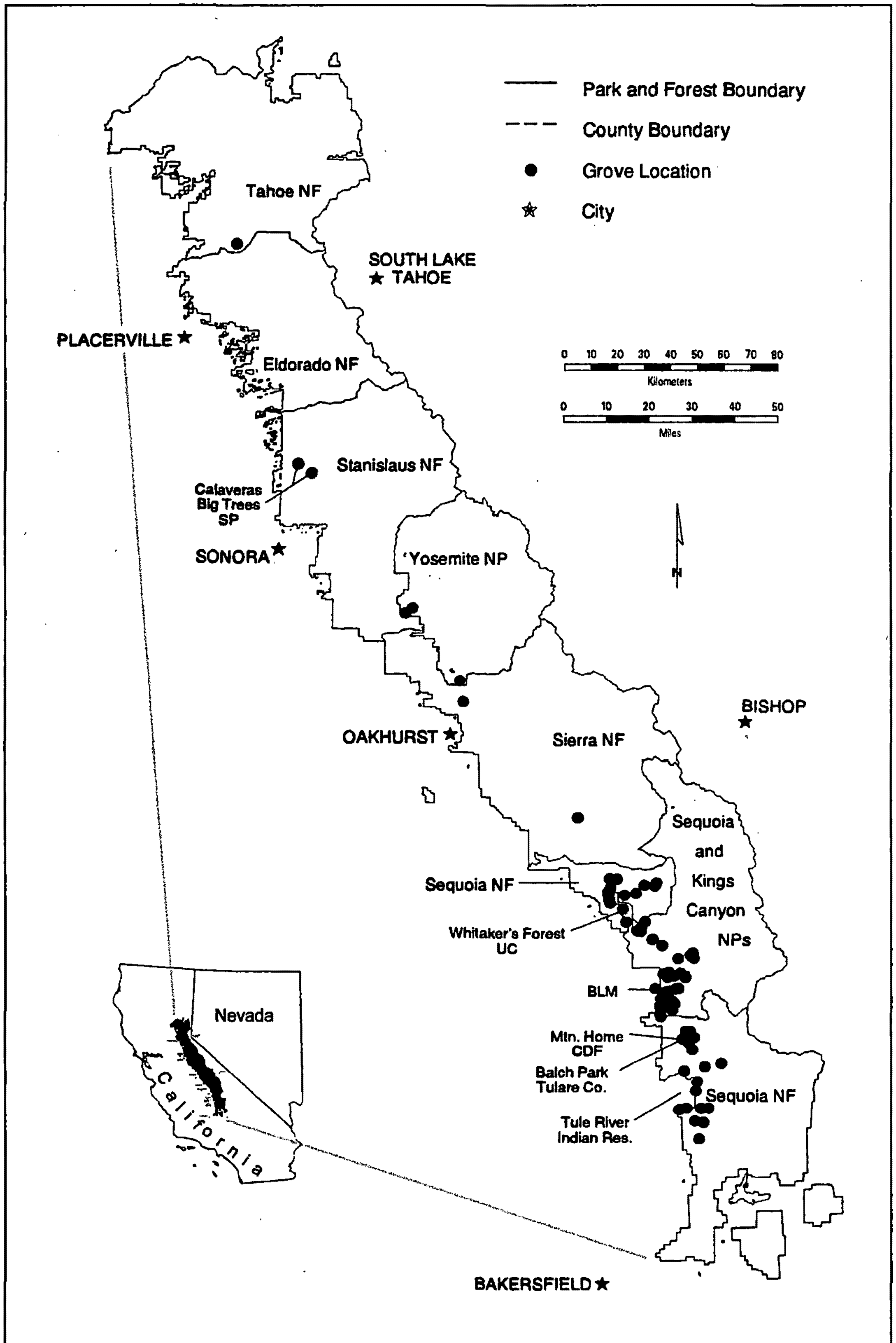

Figure 3
Locations of giant sequoia groves in the Sierra Nevada *(University of California 1996)*.

MANAGEMENT GOALS

Although the mediated settlement agreement (USDA Forest Service 1990) does not elaborate on the meaning of protect, preserve, and restore, the presidential proclamation (Bush 1992) does provide a context from which meanings useful for management purposes can be derived. In the proclamation President Bush declared: "Naturally occurring old-growth giant sequoia groves... are unique national treasures that are being managed for biodiversity, perpetuation of the species, public inspiration, and spiritual, aesthetic, recreational, ecological, and scientific values." Among other things, he proclaimed: "The designated giant sequoia groves shall be protected as natural areas with minimum development." For purposes of this paper the meaning of the goals of protect, preserve, and restore will be based on the presidential proclamation. These goals will be taken to mean:

- **Protect** naturally occurring groves from events that are contrary to or disruptive of natural ecological processes. Protect historical and prehistorical artifacts, and unusual biological and physical features within groves from agents that could destroy them or accelerate their natural rate of deterioration.
- **Preserve** the groves by allowing ecological processes, or equivalents thereof, to maintain the dynamics of forest structure and function.
- **Restore** the groves to their natural state where contemporary human activities have interfered with the natural processes--especially fire and hydrology.

The goals of protect, preserve, and restore are not independent of each other. Restoring giant sequoia ecosystems to conditions that resulted from centuries of adaptation to their environment appears to be the best way to protect them in the present, and to assure their preservation (or more appropriately, perpetuation) in the future.

PURPOSE

The purpose of this paper is to provide a scientific foundation upon which Forest Service giant sequoia grove management can be based. Specific objectives are to:

- **Define the ecosystem management** process as it applies to national forest giant sequoia groves. This is done in Chapter 2. Ecosystem management combines the social, physical, and biological dimensions of the environment in a holistic way that is particularly appropriate to the goals described above.
- **Identify elements that are key to the function of giant sequoia ecosystems.** Chapter 3 applies the second step of the ecosystem management process described in Chapter 2. It identifies processes (i.e., fire and water),

components (i.e., plant species), and structures (arrangement of components) that are important in characterizing giant sequoia groves.

- **Identify indicators** of the key elements. Chapter 4 begins the third step in the ecosystem process by identifying environmental indicators by which the key elements can be quantified.

- **Describe how measures of those indicators can vary** within naturally functioning giant sequoia ecosystems. Chapter 5 completes the third step in the ecosystem management process by quantifying and recommending an operating range for the indicators that were identified in Chapter 4.

- **Provide practical guidance on how to apply the principles** developed in Chapters 2-5. Chapter 6 presents the context, along with certain qualifications, that is necessary for the practical application of the principles developed in this paper.

SCOPE AND CONTEXT

This paper is an attempt to put existing science, accumulated knowledge, and experience to use in describing practical and attainable desired conditions for giant sequoia groves. Because it is the first attempt of this kind, at least within the Forest Service, refinement and improvement through adaptive management is expected and needed. The important thing for the moment however, is to get existing knowledge to field managers in a usable form. For that reason the paper concentrates on the ecological elements and environmental indicators that have immediate and practical application. Elements or indicators of great significance, but over which management has little or no control, are not dealt with in detail. Air pollution and climate change are examples of elements that are recognized as important (Miller et al. 1994, Anderson 1994), but not dealt with in detail.

Two important concepts are implicit throughout the document. They are:

1. Recommended management variability (RMV) includes a range of values within reference variability that implies a high degree of sustainability for the ecosystem. RMVs most often describe mid-range values under the assumption that the extremes should be rare, and will exist whether or not there is a deliberate attempt to create or maintain them.

2. Sustainability of range-wide grove attributes is not necessarily dependent on sustainability of individual grove attributes (e.g., it may be acceptable, or even desirable, for one grove to be deficit in an attribute if another grove is surplus). In fact, for certain attributes this is very much the way things work in nature. Not all giant sequoia groves are going to have trees as large as the General Sherman tree. Therefore, any proposal to correct the difference between RMV and existing conditions in a specific grove should consider whether or not it is important to take into account the existing conditions in all the other groves. For example, it may be desirable to maintain a surplus

of giant sequoia trees (a greater number than RMV) of a given size class in one grove to make up for a deficit somewhere else. On the other hand, because of the administratively derived protection goal, a surplus of fuels should rarely, if ever, be tolerated in any grove.

Finally, because field practitioners are the intended audience, the English system of measurement units is given preference over the metric. Also, common names of plant and animal species will be used.

CHAPTER 2
Ecosystem Management

This chapter provides answers to some frequently asked questions:

- What is forest management?
- What is ecosystem management?
- What, if any, is the difference?
- How is ecosystem management applied?
- What is the connection between ecosystem management and science?

FOREST VS. ECOSYSTEM MANAGEMENT

Forest management helps people achieve their goals for forests. It seeks to produce results that meet landowner expectations, whether the owners are public or private. Leuschner (1984) states: "Forest management in the broadest sense, integrates all of the biological, social, economic, and other factors that affect management decisions about the forest." The sustainability of renewable resources is a basic principle of forest management.

As defined by Manley et al. (1995) ecosystem management is "the skillful, integrated use of ecological knowledge at various scales to produce desired resource values, products, services and conditions in ways that also sustain the diversity and productivity of ecosystems. This approach blends the physical, biological, and cultural/social needs" (Figure 4).

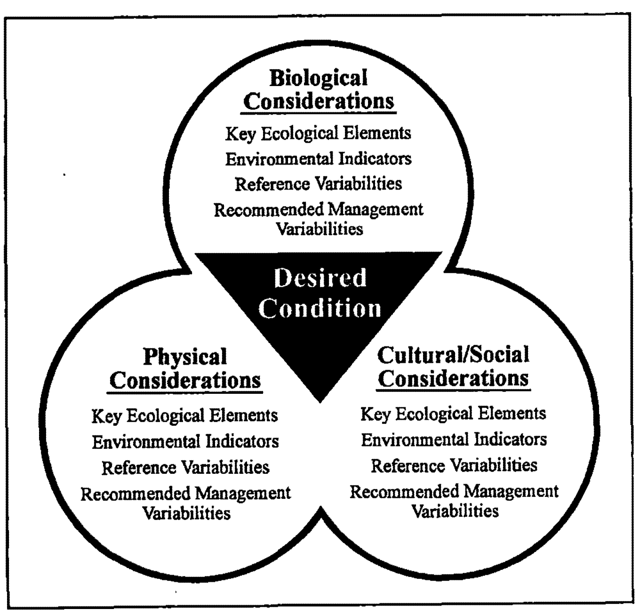

Figure 4
The USDA Forest Service Pacific Southwest region approach to ecosystem management. Biological, cultural/social, and physical considerations are integrated to arrive at a desired condition *(Manley et al. 1995).*

There appears to be no difference between the two approaches to the management of wildland natural resources, at least at the philosophical level. In practice, however, it is apparent that typical forest management plans diverge from the holistic concept expressed by Leuschner (1984) and Manley et al. (1995). Existing forest plans tend to focus on the individual components of an ecosystem, more or less in isolation from all the others. So, if the concept of ecosystem management brings anything new it is simply a reminder that all the elements of an ecosystem are interconnected, and viewing them otherwise leads to faulty assumptions about the consequences of management actions. Former Chief of the Forest Service, Dr. Jack Ward Thomas, expressed this thought when he said: "It is time to consider land use in a broader context than a series of single-use allocations to address specific problems or pacify the most vocal constituencies" (Thomas 1993).

Chief Thomas' direction to broaden the management context is consistent with the concepts expressed by Leuschner (1984) and Manley et al. (1995). This paper is a key step in implementing that direction for national forest giant sequoia groves.

CONCEPTS OF ECOSYSTEM MANAGEMENT

Many scientists and managers have written articles on the subject of ecosystem management. However, literature describing the actual practice of ecosystem management is scant. Manley et al. (1995) is a pioneering effort by field-oriented practitioners to put the concepts of ecosystem management to work on the ground. The result is a practical process for implementing ecosystem management in a well defined and systematic way. The process deals with five basic conceptual questions:

1. How did the ecosystem evolve?
2. What is sustainable?
3. What do we want [within the limits of sustainability]?
4. What do we have?
5. How do we move conditions from what we have to what we want?

These questions change the focus from <u>output</u> driven project planning which asks: "What do we need to mitigate because of our actions?", to <u>outcome</u> driven planning which asks: "What do we want to create with our actions?"

The process developed by Manley et al. (1995) involves 14 steps to be applied at the landscape level:

- Step 1--select a **landscape** to analyze
- Step 2--select key **ecosystem elements** and their **environmental indicators**
- Step 3--derive **recommended management variability** for the indicators

- Step 4--define **desired condition**
- Step 5--determine **existing condition**
- Step 6--compare **desired condition** to **existing condition**
- Step 7--identify opportunities to approach **desired condition**
- Step 8--list potential projects (**possible management practices**)
- Step 9--project selection, prioritization, and scheduling
- Step 10--**NEPA** analysis and disclosure
- Step 11--line officer decision
- Step 12--project implementation
- Step 13--monitoring and feedback
- Step 14--possible forest plan adjustment (**adaptive management**).

These steps finally provide a systematic and administratively feasible approach to ecosystem management.

CONNECTING SCIENCE TO ECOSYSTEM MANAGEMENT

Sustainable ecosystems require that the integrity of their components, structures, and processes (the three general types of elements) be maintained through time and space. This requires a reasonable understanding of how these ecosystems evolved and developed into their present state. Landscape conditions within all ecosystems are dynamic, thus measures of their elements change over time and space, but within certain limits. For example, fuels reaccumulate after fire (Parsons 1978). An understanding of this "range of variability" is critical to ensuring the sustainability of these ecosystems. Science will play a key role in providing that understanding (Piirto, Rogers, and Bethke 1997).

The remainder of this document is devoted to exploring giant sequoia ecosystem elements, understanding how they change, and describing ways in which those changes can be measured. The scope is thus confined to the first three steps outlined by Manley et al. (1995). Steps four through fourteen are largely administrative in nature. They will be dealt with in the process of implementing Forest Plan directions or developing individual project proposals.

CHAPTER 3
Selecting Key Ecosystem Elements

Ecosystem management in Region 5 of the USDA Forest Service is guided by the concepts and principles established in "Sustaining Ecosystems - A Conceptual Framework" (Manley et al. 1995). This work includes a lengthy list of ecosystem elements that could be helpful in defining and controlling the management actions in national forest giant sequoia groves. Many others could be added to the list, but if all were used in practice the administrative task would become hopelessly complex. It is therefore necessary to concentrate on just the "key" ecosystem elements (Holling 1992). These are the ones that *broadly represent the ecosystem, are influenced by management decisions*, and *are reasonably well understood* (Figure 4).

A meeting was held on December 15, 1997 to discuss ecosystem elements for giant sequoia ecosystems in general, and the Converse Basin Grove in particular. The objective of the meeting was to determine a starting point for defining key ecosystem elements to be used. That is, refine the nearly endless list of choices to a very few that make sense from both a scientific and administrative point of view, and are broadly related to (i.e., entrain) many other elements. The idea was to start simple and grow in sophistication as knowledge is gained through the practice of adaptive management (Stephenson 1996). District Ranger John Mincks, Giant Sequoia Specialist Bob Rogers, Ecosystem Manager John Exline, and Professor of Forestry Doug Piirto attended. In the view of those present, practical administrative considerations would limit selection of key ecosystem elements to between six and eight.

Key elements were chosen from the list of ecosystem elements supplied by Manley et al. (1995) with supplementation from various other sources. The following discussions on ecosystems elements are organized by hierarchical category as done by Manley et al. (1995).

ATMOSPHERIC HIERARCHY

Manley et al. (1995) list the following atmospheric elements that could be important to ecosystem management planning:

- ozone,
- particulates,
- nitrogen oxides, and
- sulfur oxides.

In the context of giant sequoia, particulate matter appears to best meet the criteria of a key ecosystem element. Smoke and dust are made visible by particulates; both are important components of the ecosystem, both are influenced by management decisions, and both are reasonably well understood.

The atmospheric hierarchy has another dimension not mentioned by Manley et al. (1995): climate. Climate is extremely important in giant sequoia ecosystem management. For example, the reintroduction of fire into giant sequoia groves must be done with a good understanding of fire history which is strongly influenced by climate (Swetnam 1993). The conditions controlling a burning prescription (e.g., fuel moisture content, fire intensity) or silvicultural prescription (e.g., selection of genetic planting stock) are affected by a range of climate variables. On the broadest scale, climate change is the single most important variable in determining long-term vegetation change. However, since climate is not likely to be influenced by management decisions, none of the components or processes associated with it are considered to be key elements.

Recommendation

Air quality and climate are important factors that must be considered when formulating management actions for giant sequoia groves. Air quality should be considered as a controlling variable in burning prescriptions, and climate should play a role in arriving at "desired condition" statements particularly for the long term. However, none of the elements associated with air quality or climate in the short term appear to be particularly useful as key elements from an administrative point of view; they are more useful as project design constraints.

CULTURAL/SOCIAL HIERARCHY

Manley et al. (1995) list the following cultural and social elements that could be important to ecosystem management planning:

- attitudes, beliefs and values,
- lifestyles and lifeways,
- social organization,
- invention and diffusion,
- land use and settlement patterns,
- population characteristics,
- economics and subsistence, and
- material culture.

The various social/cultural ecosystem elements listed above are closely interconnected, but public issues surrounding giant sequoia management most frequently involve conflicts between commodity and amenity values. This suggests that the attitudes, beliefs, and values element and the economics and subsistence element are the most significant in this case.

Dealing with the social/cultural hierarchy requires special skills and tools because this dimension transcends physical ecosystem boundaries. It includes human emotions and vicarious experiences as well as human physical needs.

Recommendation

Giant sequoia groves should be viewed as important legacies of human and natural events, not just assemblages of large, old trees. Social science should be considered on a par with the biological and physical sciences in giant sequoia management. For this reason close collaboration with both local and non-local public interests should be an integral part of giant sequoia management. Expert social scientists should be consulted to ensure that an effective approach is used in public collaboration and involvement. Tools will be needed to measure the extent of public involvement and demonstrate its impact on management decisions. The attitudes, beliefs, and values element and the economics and subsistence element should be considered the key cultural/social elements for national forest giant sequoia ecosystems.

HYDROLOGIC HIERARCHY

Manley et al. (1995) list the following hydrologic elements that could be important to ecosystem management planning:

- aquatic animal species,
- stream channel morphology,
- erosion, fire, and flooding,
- food webs,
- hydrologic cycle,
- nutrient pathways,
- organic debris,
- plant species,
- sediment, and
- water.

Many studies and anecdotal observations suggest that water is a significant factor in determining where giant sequoia groves occur in nature (Rundel 1969, 1971, 1972a,

1972b; Anderson et al. 1995). Surface and subsurface water distribution is therefore something of great concern. Stream morphology and sediment deposition are well accepted barometers of overall watershed health (Pfankuch 1978; Rosgen 1985, 1994, 1996). Water, stream morphology, and sediment appear to meet the criteria of key elements in giant sequoia ecosystems.

Recommendation

Condition of the watershed in general, and behavior of above and below ground water flow in particular, are critical to the ecology of giant sequoia groves. Therefore, channel morphology, sediment (as it relates to stream channel stability), and water (surface and subsurface flow) should be considered key hydrologic elements for giant sequoia groves.

TERRESTRIAL HIERARCHY

Manley et al. (1995) list the following terrestrial elements that could be important to ecosystem management planning:

- animal species,
- damage,
- erosion,
- fire,
- food web,
- genetic diversity,
- insects,
- nutrient cycles,
- organic debris,
- pathogens and disease,
- plant species,
- soil hydrology,
- soil productivity, and
- vegetation mosaic.

It is generally agreed that prior to the 20th century, fire was the determining factor in creating and maintaining the mixed conifer forest in which the giant sequoia groves are found (Kilgore and Taylor 1979; Harvey et al. 1980; Swetnam et al. 1991; Swetnam et al. 1992; Swetnam 1993; Caprio and Swetnam 1995; Skinner and Chang

1996). Fire was largely responsible for the vegetation mosaic that appeared on the landscape. The vegetation mosaic, and the plant species that formed it or appeared because of it, in turn provided habitat for native animal populations. (Verner and Boss [1980] describe habitats and associated wildlife species in the western Sierra Nevada.) Fire and its immediate effects on the landscape, the vegetation mosaic and associated organic debris, appear to be the most important elements in the terrestrial hierarchy.

Recommendation

Fire and the vegetation mosaic should be considered key ecosystem elements within the terrestrial hierarchy. Organic debris should also be considered a key element because this represents the fuel that profoundly affects most fire behavior. Soil hydrology and erosion are also recognized as important elements. These elements overlap with sediment and water already considered as key elements in the hydrologic hierarchy, so they will not be considered as such here.

SUMMARY AND CONCLUSION

Because of the great number of interconnections, the many ecosystem elements listed by Manley et al. (1995) can be narrowed to a very few without losing the holistic concept of ecosystem management. The narrowed list contains the key ecosystems elements of:

- attitudes, beliefs, and values,
- economics and subsistence,
- stream channel morphology,
- sediment (i.e., channel stability),
- water (i.e., surface and subsurface waterflow),
- fire,
- organic debris, and
- vegetation mosaic.

This list should be reviewed periodically as the Forest Service gains experience in the practice of giant sequoia protection, preservation, and restoration.

CHAPTER 4
Environmental Indicators

Once key ecosystem elements are identified, the next step is to determine what environmental indicators will be used to assess them. Criteria must be established to ensure that the selected environmental indicators will be useful. From a practical administrative point of view the selected indicators should:

- be affected by management actions,
- change over relatively short periods of time,
- be feasible to measure either directly or indirectly, and
- be useful in describing desired conditions.

These criteria were applied to environmental indicators of the eight key ecosystem elements identified in the previous chapter.

ATTITUDES, BELIEFS, AND VALUES ECOSYSTEM ELEMENT

Manley et al. (1995) list the following indicators of the attitudes, beliefs, and values element:

- expression of realized expectations;
- recognition and incorporation of diverse values and beliefs; and
- levels of involvement, activity, harmony, and cooperation.

Since the early 1980's NEPA scoping for activities in and around groves, administrative appeals, and litigation have provided a rich source of information on the attitudes, beliefs, and values element.

Recommendation

Public response to issues involving giant sequoia management suggest that indicators for assessing attitudes, beliefs, and values should include measurements of the:

- expression of the realized expectations (in this case the degree of compatibility between public expectations and Forest Service actions, and the effectiveness of administrative controls that ensure the faithful execution of management decisions); and
- recognition and incorporation of diverse values and beliefs (including historic as well as contemporary values).

Because of the history of controversy that surrounds giant sequoia management, social scientists, archaeologists, and historians should be consulted to help frame the context for the diversity of values and beliefs that will be encountered (Piirto, Rogers, and Bethke 1997).

ECONOMICS AND SUBSISTENCE ECOSYSTEM ELEMENT

Manley et al. (1995) list the following indicators of the economics and subsistence element:

- resources uses,
- budget,
- amount and distribution of income and employment,
- employment and economic trends,
- income levels per capita,
- tax revenues,
- rates of production/sales,
- housing availability,
- sales diversification,
- subsistence trends,
- adequacy of food, clothing, and shelter,
- and other economic statistics.

As with the attitudes, beliefs, and values element, the Forest Service has many years of experience with public issues that relate to the economics and subsistence element for giant sequoia ecosystems. A frequently raised issue not addressed by the above indicators is:

- financial feasibility.

Recommendation

Experience suggests that indicators for assessing the element of economics and subsistence should include measurements of resource uses (including both amenity and commodity uses), and the financial feasibility of carrying out the administrative decisions.

STREAM CHANNEL MORPHOLOGY ECOSYSTEM ELEMENT

Manley et al. (1995) list the following indicators of the channel morphology element:

- gradient,
- width,
- volume,
- sinuosity, confinement, and gradient (Rosgen channel types),
- depth of pools, riffles, and runs,
- pool/riffle ratios,
- width/depth ratio,
- gravel bars,
- bank steepness,
- bank stability,
- habitat inventory,
- mass movement occurrence,
- miles of stream per area of topography,
- large woody debris,
- stream class, and
- duration and size of peak flows.

Recommendation

Most of the indicators listed above fail to meet one or more of the selection criteria. Gravel bars appear to meet all criteria, but for purposes of this paper they will be considered as part of the sediment element described in the following section. However, an understanding of channel types (sinuosity, confinement, and gradient) is needed in the interpretation of sediment indicators. Rosgen (1985, 1994, 1996) classified 38 channel types using various combinations of geologic and topographic variables. For practical application on the Sequoia National Forest, Kaplan-Henry (1995) arranged these channel types into four groups. These groups are: naturally stable, stable-sensitive, unstable-sensitive-degraded, and naturally unstable. These four groups should be used to classify stream channels that are affected by giant sequoia management activities.

SEDIMENT ECOSYSTEM ELEMENT

Manley et al. (1995) list the following indicators of the sediment element:

- substrate size,
- embeddedness,
- turbidity,
- riffle-armor index,
- channel depositional features, and
- sediment sources.

Pfankuch (1978) lists 15 indicators of stream channel condition. Five of these relate to sediment through stream channel stability. The use of these five indicators is supported by Rosgen (1985, 1994, 1996) and Myers and Swanson (1992). According to Kaplan-Henry (1995) they are highly applicable to streams on the Sequoia National Forest:

- vegetative bank protection (upper banks),
- cutting (lower banks),
- deposition (lower banks),
- scouring and deposition (channel bottom), and
- percent stable material (channel bottom).

Recommendation

Deposition of sediment is a pervasive and easily observed feature of stream channels, and its use in assessing stream conditions is well established on the Sequoia National Forest. The indicators of vegetative bank protection, cutting, deposition, scouring and deposition, and percent stable material should be used to assess stream and overall watershed condition in giant sequoia groves.

WATER ECOSYSTEM ELEMENT

Manley et al. (1995) list the following indicators of the water element:

- velocity,
- turbulence,
- quantity,
- discharge,

- volume,
- depth, and
- drainage density.

Indicators not mentioned in Manley et al. (1995) but very important to giant sequoia ecosystems are:

- distribution of subsurface water,
- distribution of surface water,
- flow events that could affect the stability of monarch giant sequoia trees, and
- concentration of surface water.

Recommendation

The distribution of subsurface water is one of the most important variables in determining suitable habitat for giant sequoia groves (Rundel 1969, 1971, 1972a, 1972b; Anderson et al. 1995; Halpin 1995; Akers 1986). However, it is difficult to measure. The distribution of surface water, at least on a relatively small scale, relates indirectly to subsurface water, and it is much easier to monitor and evaluate. One indicator of surface water distribution is the drainage density. Of particular concern is if and how the existing drainage pattern is modified from the natural one. Management activities that cause water concentration are of concern because of the possible effects on tree health and stability, especially "monarch" giant sequoias. The best indicators for the water element appear to be drainage density, surface distribution, and concentration.

FIRE ECOSYSTEM ELEMENT

Manley et al. (1995) list the following indicators of the fire element:

- severity,
- size,
- distribution on the landscape,
- return rate (interval), and
- seasonality.

Recommendation

Fire severity (the effects of fire on living vegetation) is influenced by dead fuels, forest structure, topography, season of occurrence, and weather. Since fuel conditions and forest structure are responsive to management actions, and are easily

measured, severity appears to be a good indicator for the fire element. Fire return rate (i.e., interval) is another good indicator because it too can be largely controlled by management actions, and past fire history is reasonably well known.

ORGANIC DEBRIS ECOSYSTEM ELEMENT

Manley et al. (1995) list the following indicators of the organic debris element:

- volume of down material,
- number of pieces of down material,
- tons/acre of down material,
- distribution of down material,
- snag density,
- landscape connectivity, and
- size of wildlife habitat patches.

Recommendation

The weight of down material and snag density appear to be the best indicators for the organic debris element. When measured with dimensions of species, size, and decay class, these indicators all relate to major concerns of giant sequoia ecosystem management: fire behavior, wildlife habitat, and nutrient cycling. Distribution of down material should also be included because of its importance in determining fire behavior.

VEGETATIVE MOSAIC ECOSYSTEM ELEMENT

Manley et al. (1995) list the following indicators of the vegetation mosaic element:

- wildlife habitat (size, arrangement, connectivity, fragmentation etc.),
- patch size,
- patch frequency,
- canopy gap pattern,
- shape indices,
- landscape location,
- "nearest neighbor" analysis, and
- plant communities.

The vegetation mosaic is created by a diversity in plant species and age classes distributed across the landscape. In former times this diversity was maintained in large part by wildfires. (Other agents of disturbance such as floods, wind, drought, insects, diseases, and activities by native Americans also played a role). Wildfires tended to burn frequently and at low intensity over most of the landscape (Kilgore and Taylor 1979, Swetnam 1993). However, in scattered locations they burned with high intensity, creating openings (i.e., gaps) in the forest canopy where seedlings of shade intolerant plants, such as giant sequoia, could become established. The distribution of gaps in the forest canopy, and patches of vegetation along with the plants that occupy them, reasonably well define the forest vegetation mosaic.

Recommendation

The best indicators of the vegetation mosaic appear to be patch size and frequency (including gaps), and species and density of plants that make up the plant community. (Note: Gaps, patches, cohorts, and aggregations are terms used by many authors, but not always with the same meaning. Refer to the Glossary for a more complete description of the meanings as intended in this paper.)

SUMMARY AND CONCLUSION

There are many environmental indicators for the eight key ecosystem elements recognized as being critical to the management of giant sequoia ecosystems. However, only a few appear to meet all the criteria of being: affected by management actions; subject to change over relatively short periods of time; feasible to measure directly or indirectly; and useful in describing desired conditions. Indicators that appear to meet these criteria are summarized in Table 1 by the key element they represent.

Table 1
Recommended Environmental Indicators for National Forest Giant Sequoia Groves

ECOSYSTEM ELEMENTS	RECOMMENDED ENVIRONMENTAL INDICATORS
Attitudes, Beliefs, and Values	• expression of realized expectations • recognition and incorporation of diverse values and beliefs
Economics and Subsistence	• resource uses • financial feasibility
Stream Channel Morphology	• sinuosity, confinement, and gradient (Rosgen channel types)
Sediment	• vegetative bank protection (upper banks) • cutting (lower banks) • deposition (lower banks) • scouring and deposition (channel bottom) • percent stable material (channel bottom)
Water	• drainage density • surface distribution • concentration
Fire	• severity • return rate (i.e., fire return interval)
Organic Debris	• weight of down material • distribution of down material • snag density

Vegetation Mosaic	• gap and patch size
	• gap and patch frequency
	• plant community
	  • plant species
	  • plant density

CHAPTER 5
Reference Variability

Environmental indicators are to an ecosystem manager what an engine temperature gauge is to an automobile driver. Environmental indicators are a measure of ecosystem performance, and they often warn of danger at the extremes of their range. Just as the automobile engine temperature can range from below freezing on a cold day to the boiling point of the engine coolant on a hot one, environmental indicators also range between extremes. This range is referred to as **reference variability**, natural range of variability, or historic range of variability.

Manley et al. (1995) elaborate as follows: "Reference Variabilities represent the full distribution of values for environmental indicators including infrequent and extreme events (e.g., severe floods, high intensity wildfires, etc.). The role of these more extreme disturbances in maintaining ecosystem processes is not well understood, but their importance for biological elements is a well-accepted notion. It is unlikely that management activities can substantially prevent such events from occurring."

A desirable and more closely defined operating range is usually found between the extremes. This range is referred to as the **recommended management variability (RMV)**. Again Manley et al. (1995) elaborate: "The entire Reference Variability distribution is important and should be realized, for biological elements, over long-term, evolutionary temporal scales. However, planned management activities should not normally seek to replicate extreme values of the distribution if they will occur naturally." Under most conditions, properly designed and executed management actions should be able to maintain environmental indicators within the RMV, and by so doing minimize the risk of extreme events that would jeopardize ecosystem sustainability and resiliency (Figure 5).

Deriving reference variability is the next step in the ecosystem management process. But to have meaning in terms of management goals, especially restoration, two important questions need to be answered:

- What time scale should be used to evaluate the variability of environmental indicators?
- How is this variability quantified?

The recommended management variability for any ecosystem must take into account the influence of climate on forest community development (Patterson and Prentice 1985). Over long periods of time climates do change dramatically. The Sierra Nevada, for example has experienced a change from "ice age" to temperate climates over the last 25,000 to 50,000 years (Engbeck 1976). What period of time, then, best characterizes the development of ecosystems that contain the long-lived giant sequoias? For biophysical indicators Stephenson (1996) suggests that the

millennium preceding Euroamerican settlement is appropriate for this purpose (Figures 6 and 7). He summarized studies demonstrating that changes in the relative proportions of tree species slowed during this period, and grove composition was more similar to today's than during any other time period for which there is fossil evidence. (This is shown in pollen records for the giant sequoia-mixed conifer forest that go back approximately 10,000 years.)

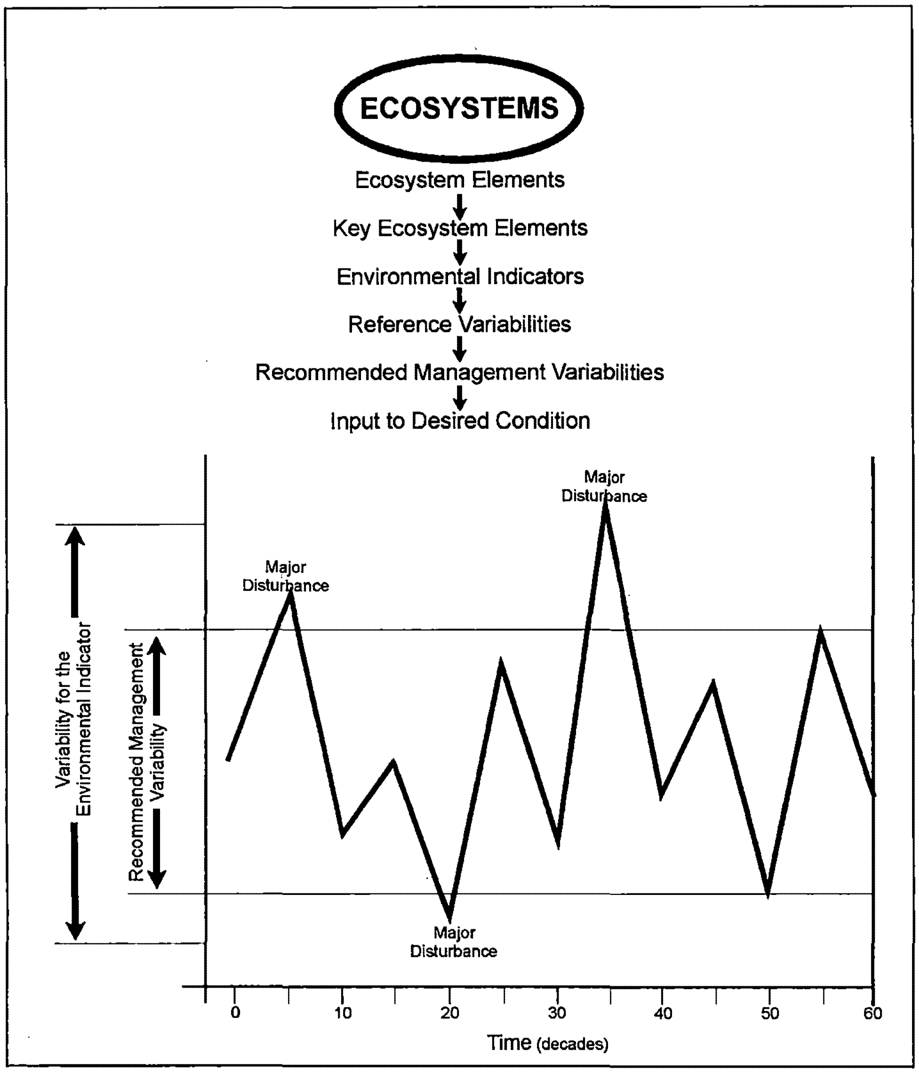

Figure 5
Relationship between ecosystem elements, indicators and recommended management variability *(Manley et al. 1995).*

Even with similar climate regimes there is substantial variation in the composition within and between the giant sequoia groves. Stephenson (1996) states in the context of the biological dimension that: "...It therefore seems reasonable to conclude that a variety of different grove structures, not a single predictable grove structure, probably occurred during periods that shared similar climates." Such variation can also be expected in the cultural/social and physical dimensions as well (e.g., soils and topography). Human attitudes and activities, for example, are likely to differ greatly between easily accessible groves near paved roads and those in wilderness.

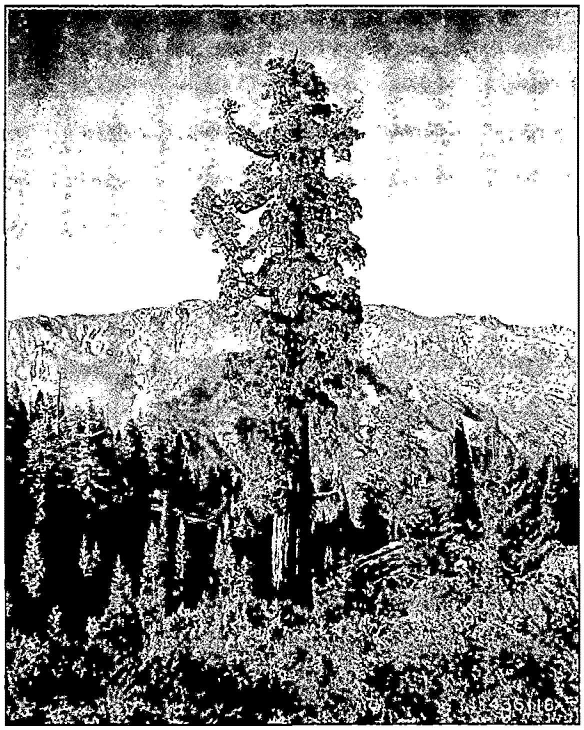

Figure 6
The Boole Tree, a remnant of the presettlement forest in Converse Basin, as it appeared in 1941. This tree lived through the millennium preceding Euroamerican settlement. *(USDA Forest Service photograph).*

The measure of variability for each selected environmental indicator is discussed here under the caption of the ecosystem element it represents. In addition, a recommendation is made for the quantification of recommended management variability. This recommendation should be considered a first approximation intended to be refined as more knowledge becomes available through the application of the adaptive management process.

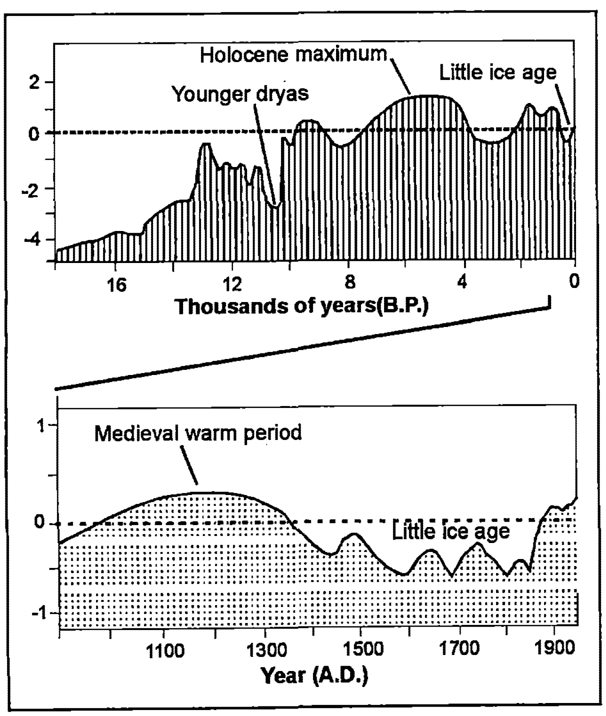

Figure 7
Global temperatures (relative changes based on oxygen isotypes) at two time scales. *(From volume II, chapter 4, University of California 1996. Reprinted by permission of the Society for Range Management.)*

ATTITUDES, BELIEFS, AND VALUES ECOSYSTEM ELEMENT

Realized Expectation Indicator

This indicator measures the degree of compatibility between expectations of Forest Service managers and forest users. The theoretical reference variability for this indicator ranges from no compatibility (0 percent), where all managers have expectations that are different from all forest users, to complete compatibility (100 percent), where all managers have the same expectations as all users. Neither extreme is likely, but the better that management goals are articulated, and the better that they are understood by both managers and users, the higher will be the compatibility of expectations.

Note that this indicator does not require agreement on management goals, just mutual understanding of them. As pointed out by Nechodom (1998), "social functionality" depends not only on effective communication; it also depends upon what is being communicated. There is no existing data from which a numerical description of this indicator can be derived. However, it is intuitively obvious that the extremes must be rare, and mid values should be frequent. Until data are available, a "normal" distribution of data values is assumed (Figure 8).

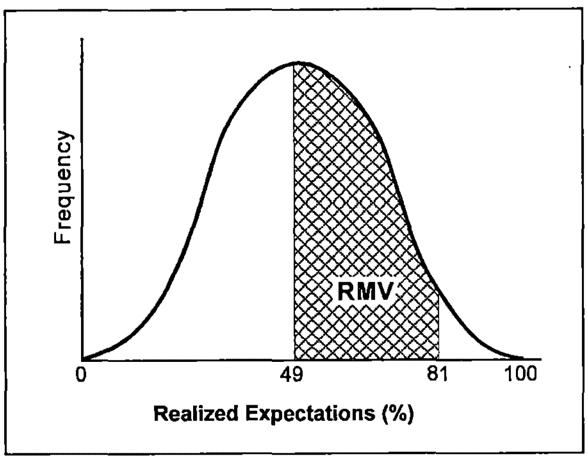

Figure 8
The **realized expectation indicator** for the Attitudes, Values, and Beliefs ecosystem element. This indicator measures the compatibility of expectations between Forest Service managers and concerned forest users. The **recommended management variability (RMV)** is 49% minimum and 81% maximum.

In the real world it is rare that members of any population all have the same expectations about any issue or question, so the practical question becomes: "How much compatibility of expectations is needed?" Automobile drivers, for example, should know all the rules; yet few drivers consider themselves irresponsible if they score less than 100 percent on a license exam. At the same time the California Department of Motor Vehicles (DMV) is willing to accept 86 percent (five wrong answers out of 36 questions). Test scores can range from 0 percent to 100 percent but DMV managers and drivers have worked out a reasonable operating range where both are satisfied if the test score is between 86 percent and 100 percent. Neither party expects less than 86 percent nor more than 100 percent.

If the Forest Service is to avoid dysfunction in the cultural/social dimension, it seems reasonable that the majority of people should share common expectations about giant sequoia management. If that majority is set at a minimum of, say, 70 percent for both managers and users, then the probability of agreement on expectations between any given manager and any given user is 49 percent (70 percent x 70 percent). At the other end of the scale, it is unreasonable to expect perfect understanding by all the parties all of the time. With limited resources it is not reasonable to hope that more than, say, 90 percent of managers and users will hold common expectations at any one time. Therefore, a realistic upper range of compatible expectations is 81 percent (90 percent x 90 percent).

Recommendation

The **realized expectations indicator** should be measured by the compatibility of expectations between Forest Service managers and concerned forest users. Until better data are available, the recommended management variability should be set at 49 percent minimum and 81 percent maximum, as shown in Figure 8. This is a case where values outside of RMV (on the high side) would be very desirable. However, since values within RMV are judged to be adequate, there is no practical reason to spend energy in trying to achieve the higher value. The status of this indicator could be determined by asking a sample population of managers and users to respond to a few simple questions about policy and procedures such as: "Do you understand the proposed action and the need for it?"

Recognition and Incorporation of Diverse Values and Beliefs Indicator

This indicator measures how well the Forest Service understands and responds to values and beliefs expressed through informal collaboration or formal NEPA scoping. It does not imply a requirement to accommodate all of those values and beliefs. With reasoning similar to the above, the scale ranges from 0 percent to 100 percent. Since the Forest Service is legally obliged to be responsive to public input, and has a tradition of dealing with public issues at the local level, the distribution of values should be skewed toward the high end of the range.

Recommendation

Because understanding and responding to public values is such a critical part of the NEPA process, the recommended management variability should be set at the high range of the scale, with little tolerance for low values. Ms. Julie Allen, Land Management Planner for the Sequoia National Forest, recommends a range of 90-95 percent for this indicator (refer to Figure 9). Data for evaluating the existing condition of this indicator do not currently exist. Data could be acquired by simply asking respondents to NEPA scoping requests if the Forest Service heard them correctly, and acknowledged their ideas or concerns in the final documentation.

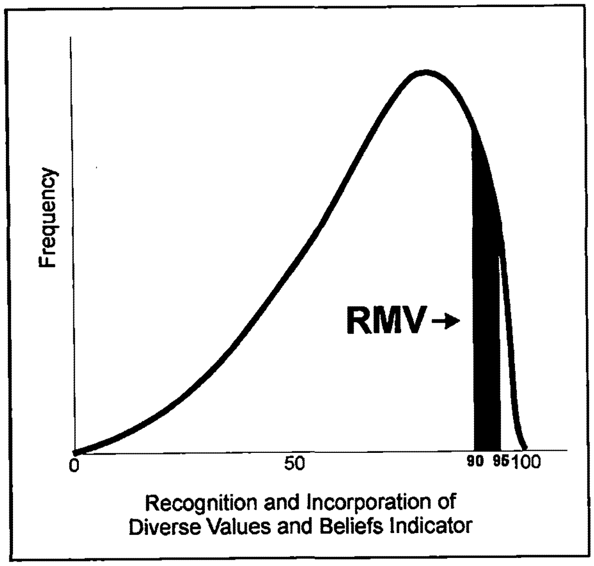

Figure 9
The **recognition and incorporation of diverse values and beliefs indicator** for the Attitudes, Values, and Beliefs ecosystem element. This indicator measures how well the Forest Service understands and responds to values and beliefs expressed through informal collaboration or formal NEPA scoping. Legal requirements imply that **recommended management variability (RMV)** should be near the high end of the range.

ECONOMICS AND SUBSISTENCE ECOSYSTEM ELEMENT

Resource Uses Indicator

The Sequoia National Forest Mediated Settlement Agreement or "MSA" (USDA Forest Service 1990) and the Presidential Proclamation (Bush 1992) set broad goals for resource use in and around giant sequoia groves. However, at the individual grove level some uses are tentative (e.g., "OHV [Off Highway Vehicle] use is subject to final determination made by the Trail Management Plan", MSA page 8), and some is indeterminate (e.g., "New mechanical/motorized uses shall not be automatically precluded within Grove Influence Zones", MSA page 8). The resources uses indicator is a measure of how fully existing forest plans or official policies deal with resource uses within giant sequoia ecosystems. Values can range from no plan or policy (0 percent) to complete direction in every detail (100 percent).

Recommendation

This indicator should be applied at the grove-specific level. Since there are no grove-specific plans or policies the indicator has no meaning at this time. This suggests an urgent need for planning at the grove level but this first requires efficacy of plans at the forest and regional levels. No measures or recommendations are given at this time.

Financial Feasibility Indicator

This indicator originates from a frequent public plea for the Forest Service to examine financial feasibility before proposing actions. A reasonable measure, then, is whether or not a financial feasibility analysis has been done before a project is proposed, that is before NEPA analysis is begun. Reference variability ranges from 0 percent to 100 percent with no intermediate values possible, that is, the analysis is either done or not done.

Recommendation

All projects should be analyzed for financial feasibility before NEPA scoping commences. The recommended management variability should be set at 100 percent. If foreseeable budgets are not adequate to execute a project proposal, but planning is still of value, this should be explained in the scoping invitation.

STREAM CHANNEL MORPHOLOGY AND SEDIMENT ECOSYSTEM ELEMENTS

These two elements will be discussed together because indicators for the sediment element only have meaning in relationship to the channel type indicator of the stream channel morphology element.

Pfankuch (1975) developed a numerical method for defining the reference variability for each of the sediment indicators. Within these ranges Kaplan-Henry (1995) described the recommended management variabilities for the Sequoia National Forest, and displayed the result as a function of channel type (refer to Table 2).

Recommendation

Stream channel grouping and recommended management variability of sediment indicators as described by Kaplan-Henry (1995) should be adopted for use in giant sequoia ecosystem management. Reference and recommended management variabilities are shown in Table 2.

Table 2

Reference and Recommended Management Variability for the Stream Channel Morphology and Sediment Ecosystem Elements Based on Pfankuch (1975) and Kaplan-Henry (1995) for Sequoia National Forest

Environmental Indicator, Pfankuch Reference Variability Recommended Variability	Naturally Stable[1] A1, A2, B1, B2, B3, C1, C2, F1, F2, G1	Stable Sensitive[1] B4, B5, B6, C3, C4, C5, C6, E3, E4, E5, E6	Unstable Sensitive[1] G2, G3, G4, G5, G6, D3, D4, D5, D6, F3, F4, F5, F6	Naturally Unstable[1] A3, A4, A5, A6 (Landslide terrain)
VEGETATIVE BANK PROTECTION				
Pfankuch Ref. Variability	1 to 12	1 to 12	1 to 12	1 to 12
Recommended Mgmt. Var.[2]	N/A	1 to 5	1 to 7	N/A
CUTTING				
Pfankuch Ref. Variability	1 to 16	1 to 16	1 to 16	1 to 16
Recommended Mgmt. Var.[3]	N/A	1 to 5	1 to 9	N/A
DEPOSITION				
Pfankuch Ref. Variability	1 to 16	1 to 16	1 to 16	1 to 16
Recommended Mgmt. Var.[4]	1 to 8	1 to 5	1 to 8	N/A
SCOURING and DEPOSITION				
Pfankuch Ref. Variability	1 to 24	1 to 24	1 to 24	1 to 24
Recommended Mgmt. Var.[5]	1 to 12	N/A	1 to 12	N/A
PERCENT STABLE MATERIAL				
Pfankuch Ref. Variability	1 to 16	1 to 16	1 to 16	1 to 16
Recommended Mgmt. Var.[6]	N/A	N/A	1 to 8	N/A

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[1] Refer to Rosgen (1985, 1994, 1996) for a detailed description of channel types (e.g., **A1**, **A2**, etc.)

[2] Recommended Management Variability for Vegetation Bank Protection of upper banks rating categories: **Excellent** (1-3) with 90 percent plant density; **Good** (4-6) with 70 to 90 percent plant density; **Fair** (7-9) with 50 to 70 percent plant density; **Poor** (9-12) with less than 50 percent plant density. **N/A** means not applicable.

[3] Recommended Management Variability for cutting of lower banks rating categories: **Excellent** (1-4) little or no cutting evident generally less than 6 inches; **Good** (5-8) some cutting intermittently at outcurves and constrictions generally between 6 and 12 inches; **Fair** (9-12) significant cutting generally between 12 and 24 inches with root mat overhangs and sloughing evident; **Poor** (13-16) almost continuous cuts evident with some over 24 inches high, failure of overhangs evident.

[4] Recommended Management Variability for Deposition of lower banks rating categories: **Excellent** (1-4) little or no enlargement of channel or point bars; **Good** (5-8) some new increase in bar formation evident most of which is from coarse gravels; **Fair** (9-12) moderate deposition of new gravel and coarse sand on old and some new bars; **Poor** (13-16) extensive deposits of predominantly fine particles with evidence of accelerated bar development.

[5] Recommended Management Variability for Scouring and Deposition of channel bottoms rating categories: **Excellent** (1-6) less than 5 percent of the channel bottom affected; **Good** (7-12) between 5 and 30 percent of the channel bottom affected; **Fair** (13-18) between 30 and 50 percent of the channel bottom affected; **Poor** (19-24) greater than 50 percent of the channel bottom is actively scouring and depositing.

[6] Recommended Management Variability for Percent Stable Material rating categories: **Excellent** (1-4) no size change evident, stable materials between 80 and 100 percent; **Good** (5-8) distribution shift is slight, stable materials between 50 and 80 percent; **Fair** (9-12) moderate change in sizes, stable material between 20 and 50 percent; and **Poor** (13-16) marked distribution change, stable materials between 0 and 20 percent.

WATER ECOSYSTEM ELEMENT

Drainage Density Indicator

Since a natural flow of water is critical to grove long-term sustainability, it follows that some measure of drainage density would be important. A potentially useful measure for this indicator was developed by Wemple et al. (1996). The authors describe a method for evaluating the addition to, or extensions of, the natural drainage pattern caused by roads. The idea is that watersheds can be evaluated for unnatural distribution of water by comparing the length of channels fed by interruptions in the natural water flow to the length of naturally conducting channels. From many comparisons of that sort, it may be possible to determine an acceptable range of drainage network extensions. The ideal, of course, is the natural drainage pattern with no unnatural extensions at all (0 percent change).

If unnatural channeling occurs within a grove, then not only is there concern about the redistribution of water, there is also a concern about the effect of concentrating water flow. If channeling occurs outside of, but upslope from the grove, the concern is whether or not the grove is being deprived of water that would naturally flow into it.

Recommendation

Methods should be developed to quantify this indicator. In the meantime each grove, including appropriate upslope distance, should be surveyed for possible water diversions and concentrations as described in the sections which follow.

Surface Distribution Indicator

The surface distribution indicator seeks to identify where the natural flow of water has been diverted. At this point in time, there is no generally agreed upon method for precisely measuring and evaluating the degree of diversion.

Recommendation

Methods should be developed to quantify this indicator. In the meantime each grove, including an appropriate upslope distance, should be surveyed for areas where the natural flow of surface water that could reach the grove has been interrupted. When found, these areas should be described, mapped, and given a subjective treatment priority rating (high, medium, low). Data should then be entered into the Forest Watershed Improvement Needs Inventory (WINI) along with a recommendation for remedial action.

Concentration Indicator

Drainage structures concentrate water by design to protect specific features (e.g., ditches protect roads by collecting, and thereby concentrating water that would

otherwise flow on the road surface). If not carefully designed drainage structure discharge can be very damaging to other features, such as monarch giant sequoia trees. Unintentional concentration of water has the same potential. As with the surface distribution indicator, there is no agreed upon method for precisely measuring the degree of concentration.

Recommendation

Methods should be developed to quantify this indicator. In the meantime each grove, including an appropriate upslope distance, should be surveyed for areas of possible water concentration. When found, they should be described, mapped, and given a subjective treatment rating priority (high, medium, low). Data should then be entered into the WINI database along with a recommendation for remedial action.

FIRE ECOSYSTEM ELEMENT

Severity Indicator

High intensity crown fires were evidently rare in the presettlement giant sequoia-mixed conifer forest (Kilgore and Taylor 1979, Muir 1961). The risk of high severity fires occurring in giant sequoia groves has increased over the last century due to a reduction in the areal extent of fire in the Sierra Nevadas. Giant sequoia mixed conifer forests now have: 1) more smaller trees with higher proportions of white fir *(Abies concolor)* and incense-cedar *(Libocedrus decurrens)* than were present historically; and 2) increased levels of fuel both on the forest floor and as fuel ladders (McKelvey et al. 1996, Skinner and Chang 1996, Stephenson 1994). Stephenson (1994) states: "By far the largest deviation from equilibrium conditions (stationary age distribution) in giant sequoia populations over the last two to three millennia is due to the effects of fire suppression during the last century."

Within this context, Shulman and Gelobter (1996) developed a preliminary wildfire severity and behavior model to evaluate potential loss of spotted owl *(Strix occidentalis)* habitat during 90th percentile weather burning conditions on the Sequoia National Forest. They used stand structure, surface fuels, slope, and weather to estimate the potential for habitat loss. They defined fire risk categories of low, moderate, high, very high, and extreme relying on BEHAVE (Fire Behavior Model) and FOFEM (First Order Fire Effects Model).

According to Mr. Jack Eaton (1996), retired USDA Forest Service Fuels Specialist, a giant sequoia grove with only 25 percent of its area in the high to extreme fire risk categories is likely to avoid crown fires even under 90th percentile burning conditions. A grove with 75 percent of its area in those categories is seriously threatened.

Recommendation

The potential for crown fires in giant sequoia groves should be kept at very low levels. However, because of considerations for the vegetative mosaic element, there should be some allowance for patches of dense, multi-layered forest cover even though it contributes to crown fire potential. The recommended management variability for the fire severity indicator should allow between 10 percent and 25 percent of the grove area to be in the high to extreme range of potential fire severity, the remainder should be moderate to low.

Return Rate (Interval) Indicator

It is generally agreed that low to moderate intensity fires in the mixed conifer forest were much more frequent prior to the late 1800's than they are today. Skinner and Chang (1996) summarized data from several authors that describe a reference variability for fire return interval of 1 to 35 years for the giant sequoia-mixed conifer forest. Swetnam et al. (1992) and Swetnam (1993) reported a fire return interval for the presettlement giant sequoia-mixed conifer forest of 3 to 8 years with a maximum interval generally less than 15 years (Figure 10). Fire-free periods of 20-30 years occasionally appeared in the record.

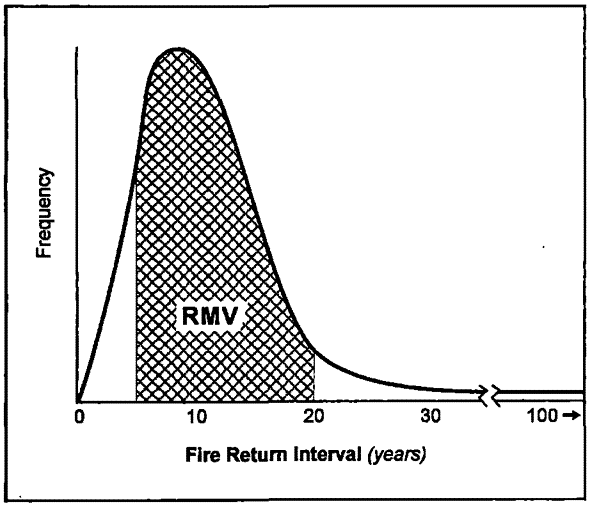


Figure 10
The **return rate indicator** for the Fire ecosystem element. Reference variability ranges from 1 to 35 years for the giant sequoia-mixed conifer forest (Shinner and Chang 1996). The **recommended management variability (RMV)** for returning low to moderate intensity fire to national forest giant sequoia groves should be in the range of 5 to 20 years.

Recommendation

Although the studies cited here were conducted on widely different scales (from 1 to 100 hectares), and include a variety of aspects and other factors that influence fire return interval, there appears to be consensus that the fine scale (on the order of 1 hectare) presettlement return interval was on the order of 10 years. If prescribed fire is used extensively, then intervals very much shorter than 10 years are likely to be logistically infeasible for management to attain. On the other hand, intervals longer than about 20 years would probably allow fuels to build to excessive levels (in excess of recommended management variability) in many cases. The recommended

management variability for returning low to moderate intensity fire to national forest giant sequoia ecosystems should be in the range of 5 to 20 years.

ORGANIC DEBRIS ECOSYSTEM ELEMENT

Weight of Down Material Indicator

Stephenson (1996) and Keifer (1995) report that existing fuel loads can vary from 19 to 134 tons per acre in groves not recently disturbed. From a fire protection point of view, the less organic debris (fuel) the better. However, this same debris provides habitat for animals and plants that are important to the ecosystem in other ways, and there are administrative constraints on how much can be removed (USDA Forest Service 1993). Rogers (1997) developed a "desired condition" for fuel within groves with this compromise in mind. However, he dealt only with fire protection, and was therefore concerned with the maximum fuel loading that would allow direct suppression under most burning conditions.

Recommendation

Until better information is available, the recommended management variability for weight of down material should be based on Rogers (1997) but modified to include minimum levels of organic debris for soil protection and other ecosystem values:

1-15 tons/acre forest floor (needle carpet and decomposing organic layer)

1-2 tons/acre for 0-1" woody material

1-3 tons/acre for 1-3" woody material

1-3 tons/acre for 3-9" woody material

10-20 tons/acre for >9" woody material

Distribution of Down Material Indicator

In 1875 John Muir observed a fire burning in the Atwell Mill Grove (Muir 1961). He noted "...fires seldom or never sweep over the trees...Here they creep from tree to tree with tranquil deliberation...Only at considerable intervals were fierce bonfires ignited where heavy branches broken off by snow had accumulated..." This observation suggests that the fuelbed matrix was relatively uniform and light -- likely on the order of 10-20 tons/acre. However, there were hot spots where fuel loading could have easily exceeded 100 tons/acre. These were the places where gaps in the forest canopy could be created, even when fires were burning under moderate weather and fuel moisture conditions.

Recommendation

Until better information is available the distribution of down material should be according to weight by size class as recommended in the previous section for at least 90 percent of the grove area. Heavier concentrations should be confined to aggregations of 1 acre or less. In the event of uncontrolled wildfire this would allow for the possibility of creating canopy gaps compatible with indicators for the vegetation mosaic ecosystem element discussed later in this chapter.

Snag Density Indicator

Little is known about how snags (dead trees) were distributed in the natural forest. However, it is likely that they appeared in a patchwork pattern as did other components of the vegetation mosaic. It is also likely that compared to the number of large snags that were produced by very old trees dying from insects and disease, there were many small ones caused by frequent fires and other agents. The small snags, however, were probably ephemeral in nature while the large ones may have endured for decades. There are no scientific studies that deal quantitatively with the snag density reference variability within giant sequoia groves.

Recommendation

Verner (1998) and McKelvey (1998) speculate that the natural rates of production and distribution of snags were so variable that it would be futile to manage for a predetermined snag density, even if the reference variabilities were known. As a practical matter they suggest simply managing for the natural forest and allowing snags to occur at their own rate and in their own pattern.

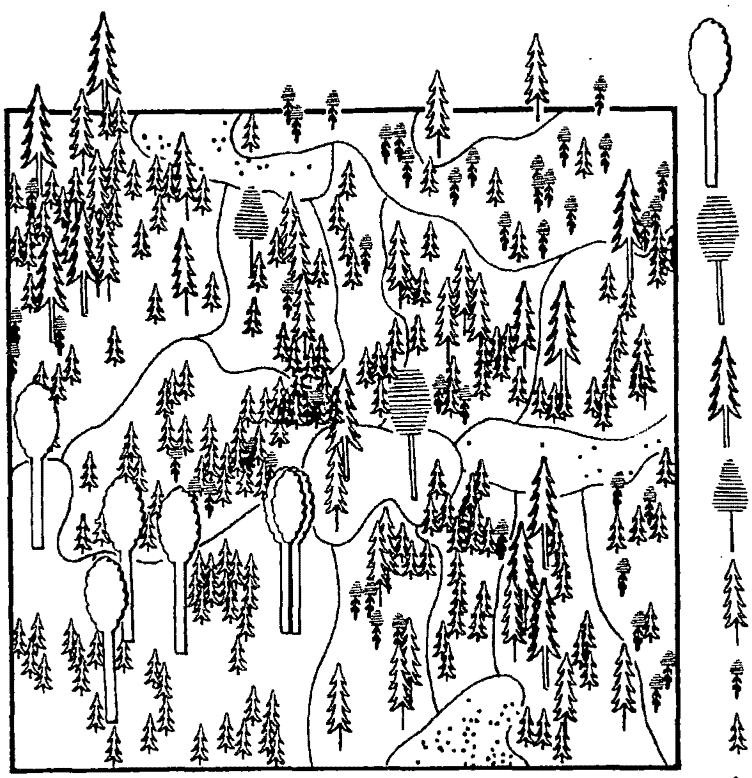
VEGETATION MOSAIC ECOSYSTEM ELEMENT

The vegetative pattern in giant sequoia groves is made up of a variety of gaps and patches. Many authors recognize this mosaic pattern as being an important attribute of the groves (Bonnicksen and Stone 1981, 1982a, b; Stephenson et al. 1991, Parsons, and Swetnam 1991; Stohlgren 1993a, b).

Huntington (1914) noted that giant sequoia trees generally grow in groups of a half a dozen trees of the same age forming a circle. Stephenson et al. (1991) report that the Parker, Senate, House, and Founders groups in Giant Forest range in size from 0.1 hectares (0.25 acres) to 0.2 hectares (0.5 acres) with 5 to 20 large giant sequoia trees of similar age. They further report that the largest cohort of giant sequoia regeneration caused by prescribed fire in Sequoia and Kings Canyon National Park is about 4 hectares (10 acres) with patchiness of giant sequoia regeneration being a function of patchiness of fire disturbance. The distribution of other vegetation follows a similar pattern. Bonnicksen and Stone (1981, 1982a, b) report that existing aggregations in Redwood Mountain Grove range in size from 135 to 1600 square meters (0.03 to .395

acres) with most overstory aggregations generally less than 800 square meters (0.20 acres).

The forest mosaic as depicted by Bonnicksen (1982a, b and 1993a, b) is illustrated in Figure 11. The boundaries of gaps and patches in giant sequoia groves are characterized as being diffuse, often without sharp edges with many gaps having living trees that survived the effects of fire disturbance (Demetry and Duriscoe 1996). This is important in that restoration work must focus both on gap and patch development and vegetation condition within the adjacent matrix areas. It is critical to realize that in the natural or "ancient" forest only a few patches (on the scale of a fraction to a few acres) may be dominated by large, old trees. However, large, old trees will be scattered throughout the forest matrix (on a scale of hundreds of acres) giving the entire landscape an "old growth", "ancient forest", or "late seral stage" character.



The tree symbols represent:

a - giant sequoias greater than 35 m (115 ft) tall

b - sugar pines greater than 35 m tall

c - white firs greater than 35 m tall

d - sugar pines 10 to 35 m (33 to 115 ft) tall

e - white firs 10 to 35 m tall

f - sugar pines 3 to 10 m (10 to 33 ft) tall

g - white firs 3 to 10 m tall

· - seedling

Figure 11

Sequoia grove structure and dynamics can be understood in terms of a mosaic of forest gaps and patches. This schematic diagram shows the location of trees in a 50 m by 50 m (164 ft by 164 ft) section of the Redwood Mountain Grove, unburned for about a century. Lines are meant to accentuate the forest mosaic by delimiting patches of relatively uniform forest structure and composition, though it is clear that patch boundaries are not always distinct and their designation can be somewhat arbitrary. For clarity, the tree symbols are reduced in size relative to the plot, lending a somewhat open appearance to the stand. *(Adapted from Bonnicksen and Stone [1982a, b and 1993a, b], with permission of the Ecological Society of America.)*

Gap and Patch Size Indicator

Demetry and Duriscoe (1996) studied fire-caused gaps as part of the research needed for ecological restoration of Giant Forest Village in Sequoia National Park. They analyzed the vegetation response in 18 gaps of three different sizes that were created by prescribed fire within the last 15 years:

1. small gaps from 0.067 hectares (0.16 acres) to 0.097 hectares (0.239 acres) with a mean of 0.086 hectares (0.212 acres);

2. medium gaps from 0.15 hectares (0.37 acres) to 0.24 hectares (0.59 acres) with a mean of 0.20 hectares (0.49 acres); and

3. large gaps from 0.34 hectares (0.84 acres) to 1.17 hectares (2.89 acres) with a mean of 0.67 hectares (1.65 acres).

Stephenson et al. (1991) and Stephenson (1994) reported even-aged patches ranging in size from 0.03 to 0.4 hectares (0.08 to 1.0 acres). The minimum size of gap leading to successful recruitment of giant sequoia appeared to be around 0.1 hectares (0.25 acres), to the nearest order of magnitude. Gaps larger than 10 hectares created by avalanches or single or repeated fires are reported as being a rare occurrence within most presettlement giant sequoia groves (Fry 1933, 1948; Stephenson et al. 1991; Caprio et al. 1994; Stephenson 1994, 1996).

Stephenson (personal communication: 1998) speculates that perhaps two thirds of all gaps in presettlement times were less than one half acre in size. Based on work in the Redwood Mountain Grove, Bonnicksen (1993a, b) states that even-aged groups of trees in ancient forests were generally less than 0.2 acres in size. However, the gaps from which these groups developed were probably larger than that (Stephenson 1987).

Available information suggests that most gaps created by natural causes within giant sequoia groves probably ranged from 0.1 to 3 acres in size as shown in Figure 12. This figure is constructed from an estimate of presettlement distribution of gaps of different sizes based on work by Stephenson (personal communication: 1998) and Bonnicksen and Stone (1978, 1982a).

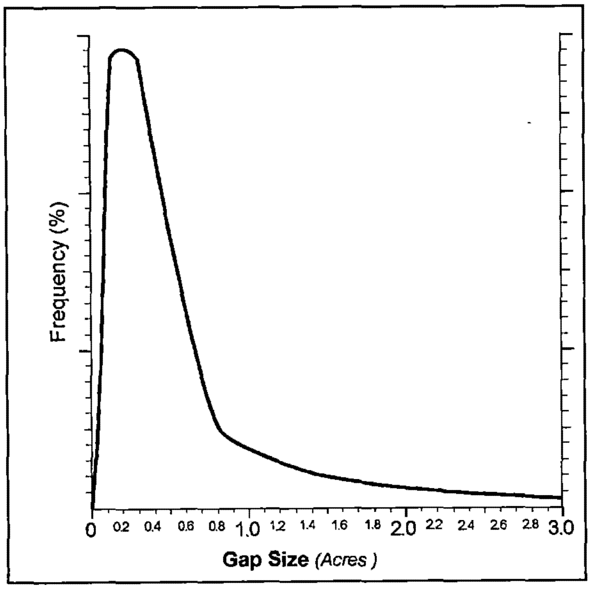


Figure 12
The **gap size and frequency indicators** for the Vegetation Mosaic ecosystem element. An approximation based on anecdotal data provided by Stephenson (1998) and empirical data in Bonnicksen and Stone (1981, 1982a, b), Stephenson (1994, 1996), Stephenson et al. (1991), Caprio et al. (1994), Demetry and Duriscoe (1996). Even though two-thirds of all presettlement gaps were probably less than 0.5 acres, they accounted for only one-third of all gap area.

Recommendation

Most gaps and patches of vegetation that arise from them, should be on the order of 0.2 acres. The recommended management variability should range from 0.1 to 2.0 acres (Figure 12).

Gap and Patch Frequency Indicator

No empirical data exists to verify the exact amount of area within a giant sequoia grove that was disturbed during any given period in presettlement times. However, some clues to this question can be gained from Bonnicksen and Stone's (1982a, b) work. They estimated that in 1890 the Redwood Mountain Grove contained 7 percent of the area in aggregations dominated by bare soil (gaps), 6 percent grass and forbs, 10 percent seedling trees (trees less than 3 meters in height), 19 percent brushland, and 17 percent saplings (trees between 3 and 10 meters in height). These conditions suggest that about 13 percent of the area was subject to recent disturbance (the bare soil, grass and forb aggregations). Stephenson (personal communication: 1998) suggests gaps created within a given decade probably occupied significantly less than 10 percent of the landscape. This is consistent with the 7 percent bare soil area estimated by Bonnicksen and Stone (1982a, b). Bonnicksen and Stone (1982a, b) also estimate that 15 percent of the area was dominated by pole-size trees (trees between 10 and 35 meters in height), 9 percent by mature trees (greater than 35 meters in height but less than 1.2 meters in diameter breast height), 10 percent by large mature trees (greater than 35 meters in height and greater than 1.2 meters in diameter breast height), and 7 percent was occupied by rock or unclassified vegetation (Figure 13).

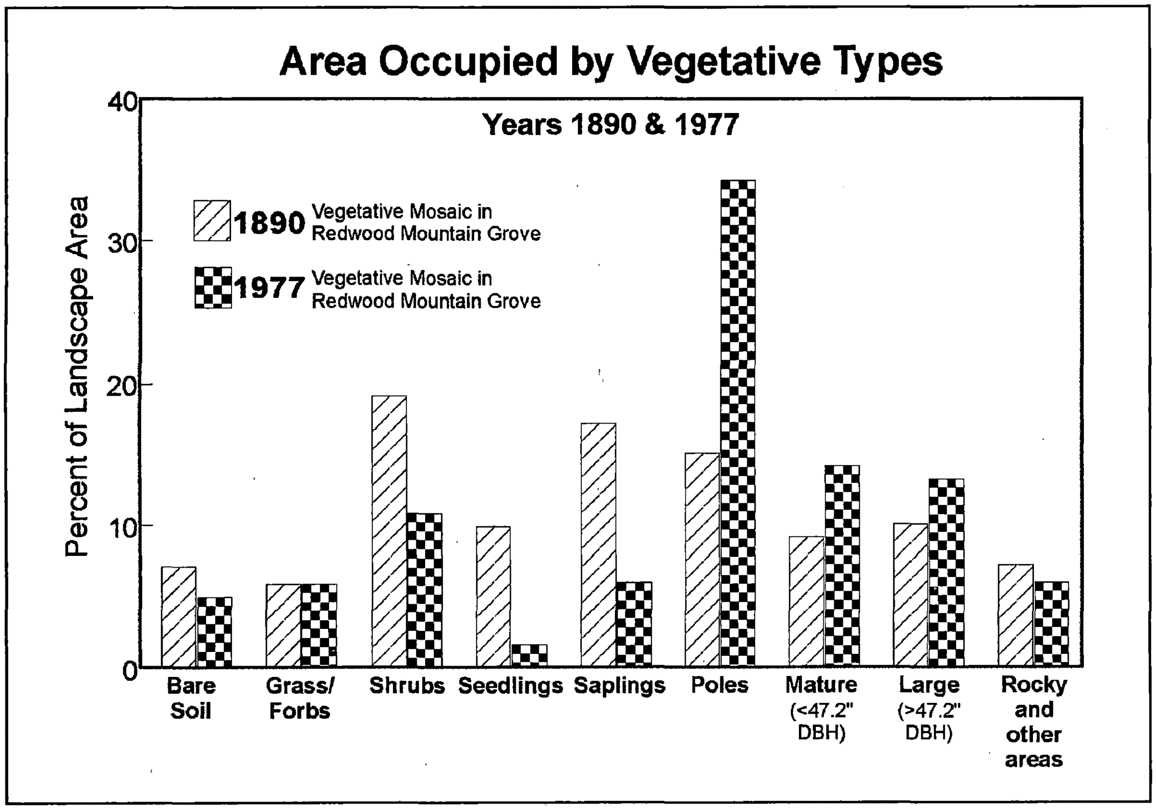


Figure 13
The plant community indicator of landscape area for the Vegetation Mosaic ecosystem element based on empirical data provided by Bonnicksen and Stone (1982a, b) for Redwood Mountain Grove. Illustrated in this figure is the estimated amount of landscape area occupied by different vegetation types. A similar shift in vegetation types has been anecdotally observed for other national forest giant sequoia groves.

Recommendation

- Recently created gaps in the forest canopy (less than 10 years old), other than sites with unproductive soils, should occupy 1-10 percent of the grove area.
- Early seral stage patches (vegetation 10-20 years old) should dominate on 30-40 percent of the grove area.
- Mid-seral stage patches (20-150 years old) should dominate on 40-50 percent of the grove area.
- Patches of late seral stage vegetation (greater than 150 years old) should dominate on 10-20 percent of the grove area.

Consideration should be given to the fact that gap and patch boundaries tend to be diffuse and that remnants of seral stages other than the dominant one can occupy portions of a gap or patch. There can be "young" understory vegetation in late seral

patches, and "old" overstory in early seral patches, and various other combinations within a given gap or patch.

Plant Community Indicator

According to Rundel (1971) giant sequoia groves are differentiated from adjacent mesic habitats in the mixed conifer forest only by the presence of giant sequoia. Rundel (1971) states "No other species is even partially restricted in its distribution to these groves." Other plant species in giant sequoia groves probably vary in abundance in response to the same conditions that promote the giant sequoia. Pacific dogwood *(Cornus nuttallii)*, for example, is a moisture-loving plant. It frequently seems to be more prevalent in giant sequoia groves than the surrounding forest. It appears that there have been no changes in the dominant trees species present in giant sequoia groves when compared to presettlement times, but there have been dramatic changes in density, age structure, and the overall vegetation pattern (Stephenson 1996). Other studies that characterize both understory and overstory vegetation in contemporary giant sequoia groves include: Schubert and Beetham (1962); Hartesveldt and Harvey (1967); Kilgore (1968, 1972); Kilgore and Biswell (1971); Hartesveldt, et al. (1975); Kilgore and Taylor (1979); Harvey, et al. (1980); Bonnicksen and Stone (1980); Burns and Honkala (1990a); Weatherspoon (1990); Stohlgren (1991, 1992, 1993a, b); Skaggs (1996); and Demetry and Duriscoe (1996).

There is general agreement that the absence of fire in most of the giant sequoia groves has resulted in an increase of white fir, reduced regeneration of giant sequoia and pines, and reduced density of shrubs and hardwoods (Hartesveldt and Harvey 1967, Rundel 1971, Kilgore 1972, Kilgore and Biswell 1971, Kilgore and Taylor 1979, Harvey et al. 1980, Bonnicksen and Stone 1982a, b, Burns and Honkala 1990a). Bonnicksen and Stone (1982a, b) found that the proportion of the area occupied by conifer aggregations has increased from 49 percent in 1890 to 63 percent in 1977. The number of aggregations dominated by white fir increased from 27 percent in 1890 to 37 percent in 1977. However, Bonnicksen's work has been criticized by Stephenson (1987) who points out a probable bias toward underestimating the amount of white fir in 1890, particularly in the overstory.

Considerable information is available on tree stocking density for the mixed conifer forest in general (Dunning and Reineke 1933), but little is available for how it combines with the giant sequoia component within giant sequoia groves. Stephenson (1994) discusses age distribution and Stohlgren (1991, 1992, 1993a, b) discusses basal area and tree distribution of giant sequoias within selected groves. Rundel (1971) provides valuable information on basal area and frequency of occurrence by major tree species within groves. All of these studies are contemporary; the data include changes that have occurred during the past 100-150 years of "settlement". Nevertheless, they do provide a basis for speculating on how the presettlement groves may have been structured.

Stohlgren's data (1991), for example (Figure 14), shows that over 90 percent of the existing giant sequoia basal area is in trees larger than about 60 inches in diameter. Trees of this size were almost certainly well established at least 100 years ago, and probably persisted with about the same mortality that would be expected even with the periodic low intensity fires of presettlement times. Thus, except for perhaps 10 percent of the total basal area, contemporary basal area distribution for giant sequoias appears to be a reasonable representation of the presettlement distribution. For the part of the range that represents structure development during settlement times, one can speculate that the basal area in larger trees (say between 30 and 60 inches in diameter) probably over-represents presettlement times because these trees did not experience significant thinning by fire. On the other hand basal area in the smaller trees is probably under-represented because seedlings were not being established in the undisturbed, closed canopy forest (Stephenson 1994).

Rundel (1971) provides data on basal area distribution (relative dominance) by species in four groves. However, these data may not give a close approximation to presettlement conditions because, compared to giant sequoia, less of the mixed conifer basal area persists from presettlement times. Willard (1995) provides anecdotal data that helps with the interpretation of mixed species within giant sequoia groves. He analyzed 23 sets of cruise data taken in five groves between 1908 and 1936. (All but five of the sets were taken in 1908.) Giant sequoia ranged from 57 to 87 percent of the total merchantable board foot volume, the average being 73 percent. Although cruise procedures are unknown it is almost certain that the basal area proportion of giant sequoia was less than the cruise proportion. This is because cruise volume is a function of basal area times height, and the giant sequoia trees that account for most of the basal area are taller than most mixed conifers. Thus for the same volume, giant sequoias require less basal area than the mixed conifers. Some of this difference, which could be on the order of 40 to 50 percent, could be offset by breakage estimates used by the cruisers. They surely estimated greater breakage, and hence a proportionally lower net volume, than in the mixed conifers. If Willard's giant sequoia volume proportion is reduced by, say, 10 percent to compensate for giant sequoia height and breakage differences, Willard's data corroborates Rundel's very well. Rundel's (1971) data on four groves averages 65 percent dominance (basal area) for giant sequoia, Willard's (based mostly on 1908 data) would estimate 63 percent on average. Surprisingly, it appears that contemporary relative dominance by species is similar to presettlement times. This probably is not true for the mixed conifer forest in general where there has been significantly more disturbance. However, even here McKelvey and Johnston (1992) estimate only a 10-20 percent shift toward white fir dominance.

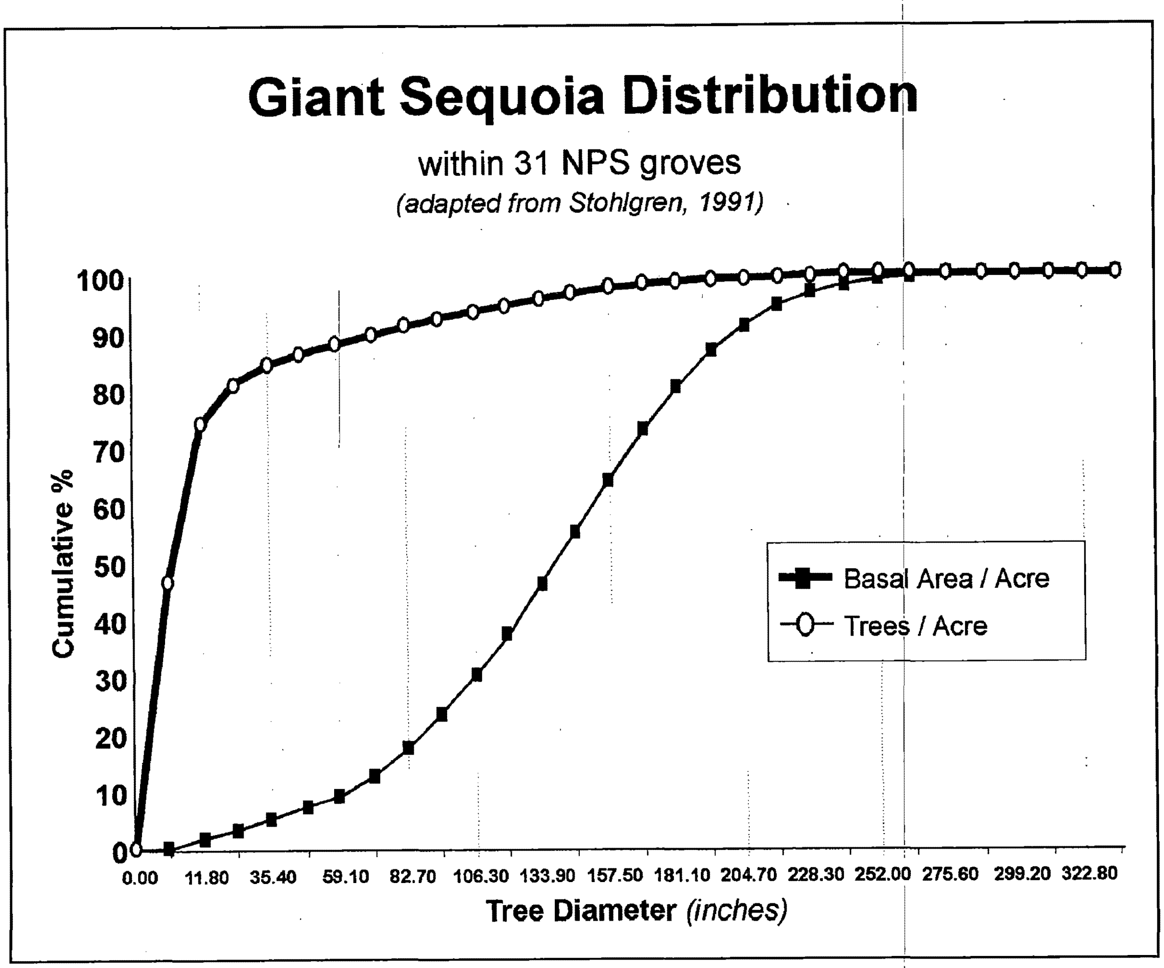


Figure 14
Distribution of giant sequoia trees as expressed by numbers of trees and basal area per acre (cumulative frequency).

However, the same cannot be said about relative density (numbers of trees per acre). In contemporary groves Rundel (1971) shows that giant sequoias number between 5 and 11 percent of the total trees present, with white fir making up between 54 and 85 percent of the total. Many scientists suggest that there were many more young giant sequoias and fewer white fir trees in presettlement times (Hartesveldt and Harvey 1967, Rundel 1971, Kilgore 1972, Kilgore and Biswell 1971, Kilgore and Taylor 1979, Harvey et al. 1980, Bonnicksen and Stone 1982a, b, Burns and Honkala 1990a). Muir (1961) corroborates this suggestion with anecdotal observations such as: "On a bed of sandy ground 15 yards square, which had been occupied by four sugar pines, I counted ninety-four promising seedlings, an instance of sequoia gaining ground from its neighbors. Here also I noted eighty-six young sequoias from 1 to 50 feet high on less than half an acre of ground that had been cleared and prepared for their reception by fire." Willard (1995) does not have corroborating evidence from cruise data. However, it is safe to say that young giant sequoias (seedlings to trees perhaps 30 inches in diameter) were relatively more abundant and other species, primarily white fir, were less abundant in presettlement times.

Recommendation (plant species)

Intuition suggests that for ecosystem resilience and stability the array of plant species currently existing (other than exotics) should be maintained. Until better information is available, no other species should be introduced and seeds for giant sequoia planting within a grove should come from trees within that grove (Biswell 1975, Fins and Libby 1982, 1994). Until more is known about their presettlement distribution, the abundance of shrubs and herbaceous plants should be allowed to vary according to their natural propagation following natural or management induced disturbance.

Based on work done by Rundel (1971), Stohlgren (1991), and Willard (1995):

- Within groves giant sequoias should occupy approximately 55-75 percent of the total basal area and should make up at least 10 percent of the total number of trees.
- The mixed conifer component within groves should contain 25-45 percent of the total basal area, white fir being the dominant species. Incense-cedar, sugar pine *(Pinus lambertiana)*, ponderosa pine *(Pinus ponderosa)*, and black oak *(Quercus kelloggii)* are also important components of most groves, but even in combination should rarely occupy more than 20 percent of the total basal area.
- Less common associates of the mixed conifer component include Jeffrey pine *(Pinus jeffreyi)*, Douglas-fir *(Psuedotsuga menziesii)*, red fir *(Abies magnifica)*, Pacific yew *(Taxus brevifolia)*, Pacific dogwood, California hazel *(Corylus cornuta* var. *californica)*, white alder *(Alnus rhombifolia)*, Scouler willow *(Salix scouleriana)*, bigleaf maple *(Acer macrophyllum)*, bitter cherry *(Prunus emarginata)*, and canyon live oak *(Quercus chrysolepis)*. No recommendations for these species are made at this time, other than to recognize their legitimacy.

Recommendation (plant density)

As discussed above, estimating a reasonable recommended management variability for plant densities (trees per acre by size and species) is highly problematical, at least in the smaller size classes. For sustainability on a scale of 10's or 100's of acres, though, it is obvious that to account for mortality each smaller size class must have progressively more members than the preceding one. Table 3 illustrates one such distribution for giant sequoia. It is based on Stohlgren's (1991) work for the larger sizes with intuitive estimates for the smaller sizes. To simplify practical application in the field Table 4 condenses Stohlgren's complete set of data given in Table 3 and depicted graphically in Figures 14, 15, and 16. For other tree species it is assumed that they will be distributed in a similar (uneven-aged) fashion. Guldin (1991) provides one approach for defining the relationships between size (as a proxy for age), number of trees, and basal area per acre. By combining the work of Rundel (1971) and Stohlgren (1991) one can conclude that average basal area stocking for

groves should be on the order of 210 square feet per acre for giant sequoia and 110 square feet per acre for other species. (Note: These figures include the basal area of trees that exist in the forest as a result of fire suppression in the last century. However, the contribution of these trees to total basal area is relatively small, as shown in Figure 14, especially in the case of giant sequoia, because most of the basal area is accounted for in trees older than 100 years.)

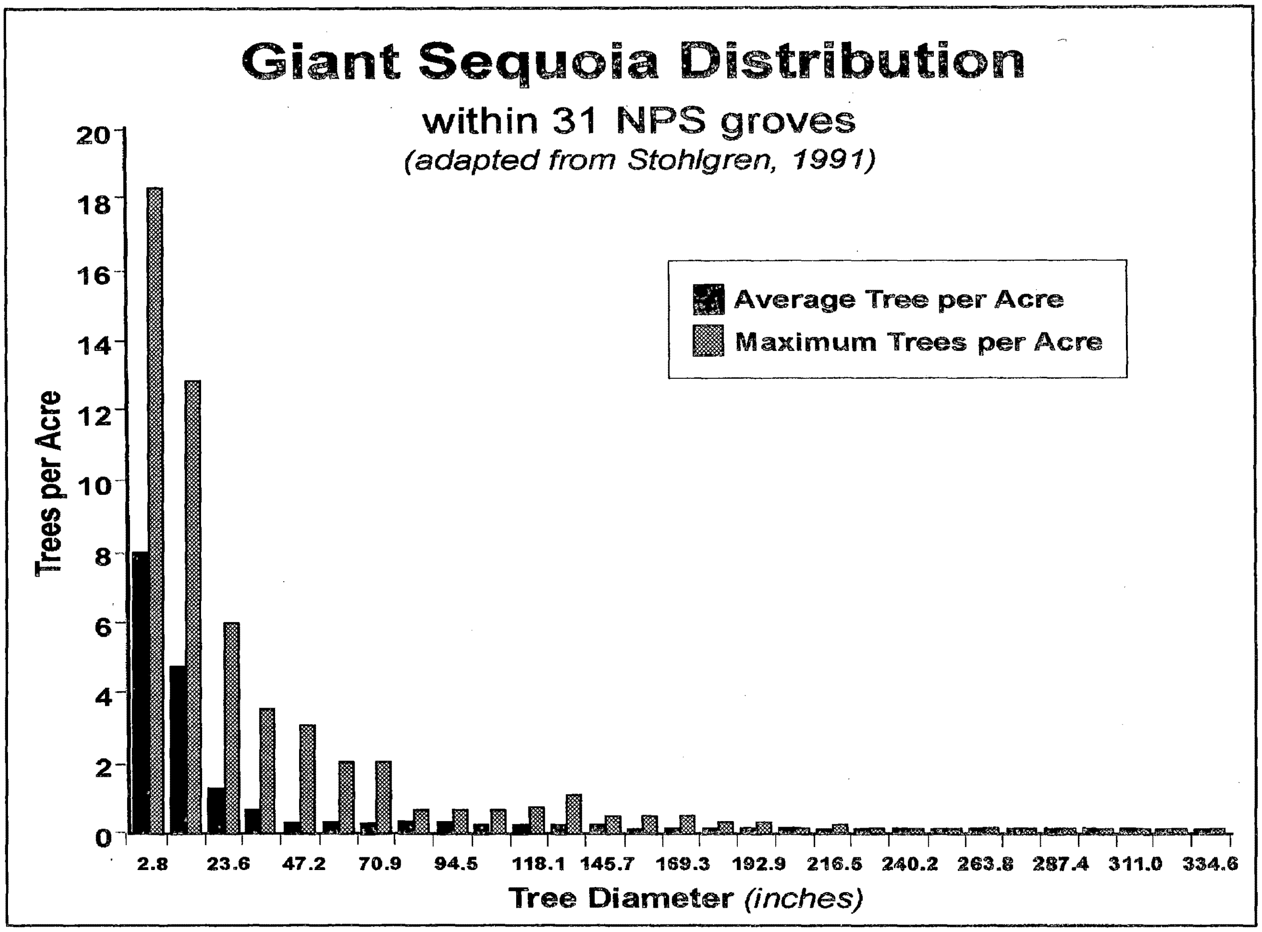


Figure 15
Distribution of giant sequoia trees as expressed by numbers of trees per acre.

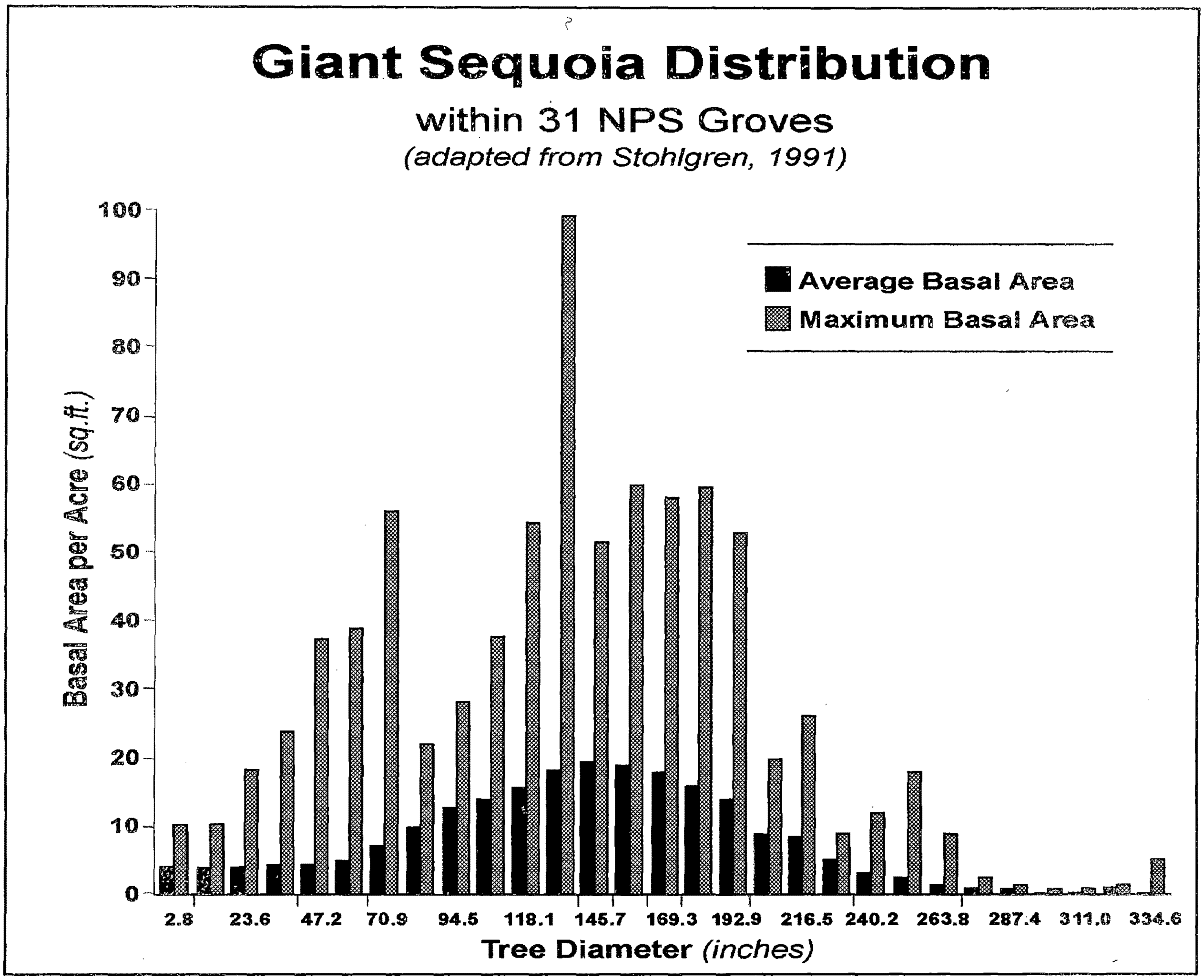


Figure 16
Distribution of giant sequoia trees as expressed by basal area per acre.

Table 3

Reference Variability for Number of Giant Sequoia Trees (TPA) and Basal Area Per Acre (BA/Acre)[1]

Diameter Class *(inches)*	Average Trees/Acre	Range of Trees/Acre	Average BasalArea/Acre *(sq. ft.)*	Range of BasalArea/Acre *(sq. ft.)*
2.8	7.9	0.0 to 18.2	0.3	0.0 to 0.8
11.8	4.6	0.1 to 12.8	3.5	0.1 to 9.8
23.6	1.2	0.2 to 5.9	3.7	0.6 to 18.0
35.4	0.6	0.1 to 3.4	3.8	0.5 to 23.4
47.2	0.3	0.0 to 3.0	3.9	0.0 to 37.0
59.1	0.3	0.1 to 2.0	4.8	1.0 to 38.5
70.9	0.3	0.0 to 2.0	6.9	0.0 to 55.4
82.7	0.3	0.0 to 0.6	9.6	0.0 to 21.3
94.5	0.3	0.0 to 0.6	12.4	0.0 to 27.6
106.3	0.2	0.0 to 0.6	13.6	0.0 to 37.4
118.1	0.2	0.0 to 0.7	14.9	0.0 to 53.9
133.9	0.2	0.0 to 1.0	17.8	0.0 to 98.9
145.7	0.2	0.0 to 0.4	19.2	0.0 to 51.1
157.5	0.1	0.0 to 0.4	18.8	0.0 to 59.7
169.3	0.1	0.0 to 0.4	17.3	0.0 to 57.5
181.1	0.1	0.0 to 0.3	15.3	0.0 to 59.3
192.9	0.1	0.0 to 0.3	13.4	0.0 to 52.3
204.7	<0.1	0.0 to 0.1	8.5	0.0 to 19.6
216.5	<0.1	0.0 to 0.2	7.8	0.0 to 25.9
228.3	<0.1	0.0 to 0.1	4.7	0.0 to 8.5
240.2	<0.1	0.0 to 0.1	2.9	0.0 to 11.6
252.2	<0.1	0.0 to 0.1	1.9	0.0 to 17.5
263.8	<0.1	0.0 to 0.1	0.8	0.0 to 8.9
275.6	<0.1	0.0 to 0.1	0.4	0.0 to 1.8
287.4	<0.1	0.0 to 0.1	0.2	0.0 to 0.9
299.2	<0.1	0.0 to 0.1	0.1	0.0 to 0.5
311.0	<0.1	0.0 to 0.1	0.1	0.0 to 0.3
322.8	<0.1	0.0 to 0.1	0.2	0.0 to 0.8
334.6	<0.1	0.0 to 0.1	0.1	0.0 to 4.8

[1] The average and range of values shown are based on studies completed by Hammon et al. (1964, 1970, 1975, 1976), Western Timber Service (1970), Stohlgren (1991) for 31 national park giant sequoia groves containing 30 or more giant sequoia trees.

Table 4
Recommended Management Variability (RMV) for Giant Sequoia Trees[1]

DBH Size Group *(inches)*	Average Trees/Acre	RMV for Trees/Acre Range	Average Basal Area / Acre *(sq. ft.)*	RMV for Basal Area /Acre Range *(sq. ft.)*
0.1 to 5.9	7.9	10 to 40[2]	0.3	0.2 to 0.6
5.9 to 17.7	4.6	5 to 20[2]	3.5	0.5 to 1.5
17.7 to 29.5	1.2	2 to 10[2]	3.7	1.0 to 4.0
29.5 to 65.0	1.2	1 to 4	12.5	4.0 to 16
65.0 to 112.2	1.1	1 to 2[3]	42.5	14 to 41
112.2 to 187.0	0.9	0 to 2[3]	103.3	0 to 119
>187.0	0.1	0 to 2[3]	41.1	0 to 331
TOTAL	17		206.9	

[1]Recommended management variability is based on a complete giant sequoia tree inventory of 31 national park groves with more than 30 giant sequoia trees present (Hammon et al. 1964, 1970, 1975, 1976; Western Timber Service 1970; Stohlgren 1991). Original grove size estimates used by Stohlgren were modified to reflect current information. Stohlgren estimated 8,277 acres (3,351 hectares), current estimates show 9,665 acres (3,913 hectares) in the 31 national park groves. This difference in size affects per hectare and per acre calculations and explains why numbers shown here do not correspond directly to Stohlgren's per hectare values.
[2]Probable range needed for sustainability - not substantiated by empirical or other data.
[3]No giant sequoia grove is known to have on average more than 2 trees per acre in these size classes.

CHAPTER 6
Interpretation and Application

OVERVIEW

The information provided in this paper is intended to serve as an ecological foundation for site-specific grove management planning. It is expected that scientific principles and methods will be applied to monitor management activities that are based on what is presented here. As scientists add to the body of giant sequoia knowledge, and as monitoring provides feedback on the short- and long-term effects of management actions, adaptive management will create a strong link between science and management of national forest giant sequoia ecosystems. The purpose of this chapter is to provide a context for the practical application of what is presented in Chapters 3-5.

COMPLETING THE ECOSYSTEM MANAGEMENT PROCESS

This paper has concentrated on giant sequoia ecosystems, their elements, associated environmental indicators, and reference variability. These are critical variables in the process of ecosystem management planning, but identifying and quantifying them only completes three steps out of the 14-step Manley et al. (1995) process discussed in Chapter 2 of this paper. The context in which ecosystem elements and environmental indicators are applied in practice must take into account all 14 steps in the planning process with significant emphasis on Steps 1 and 14 (landscape to analyze and adaptive management).

SELECTING THE LANDSCAPE AREA

The first step in the Manley et al. (1995) ecosystem management process is to select a landscape for analysis. The focus of this paper is on grove ecosystems, the boundaries of which are defined by the outermost giant sequoia trees within the groves. It does not attempt to deal with external influences except in the case of the water element. However, it is obvious that the ecosystem management process must take into account the larger landscape of which the groves are a part. There are two levels of consideration as to the appropriate answer for the question "what is an acceptable area to protect, preserve (i.e., conserve), and restore a national forest giant sequoia grove?"

First Level of Analysis

The first level of consideration must focus on what amount of land area to map as being a "distinct" giant sequoia grove. It was recognized in the SNEP report (University of California 1996b) that mapping of giant sequoia groves "...is enormously complicated by irregular patterns of naturally occurring giant sequoia

trees, rugged topography, and the importance of identifying the full area of ecosystem influences for each grove." The Mediated Settlement Agreement (USDA Forest Service 1990) requires that the tree line area plus a buffer zone of 500 or 300 feet be established for national forest giant sequoia groves outside of wilderness or other protected areas. Precise boundaries for all national forest giant sequoia groves are now known, a major contribution to science and a good starting point from which to begin the grove management planning process.

Second Level of Analysis

The second level of analysis must then address how factors external to the grove area affect it and whether or not feasible management actions can be undertaken to control these factors. Little can be done at the grove management plan and project level to control year-long air pollution originating from distant areas but a lot can be done to reduce the risk of catastrophic fire moving into a giant sequoia grove from high fire risk areas (e.g., adjacent chaparral and densely stocked forested areas). Thus the second level of analysis should focus on what the SNEP report (University of California 1996b) describes as ecologically based influence zones to insure the long-term health of national forest giant sequoia groves.

A rational approach to defining the ecological influence zone for giant sequoia groves should definitely take into account two of the key elements identified in this paper: fire and water (Rundel 1972b, Anderson 1995, University of California 1996b). Using this approach, and with only rudimentary knowledge of fire behavior and hydrology, leads to the conclusion that sub-watersheds that contain the groves should be the landscape of concern. More specifically, fire influence is of concern in those portions of the sub-watershed that lie below the grove, and water influence is of concern for those portions that lie directly above.

MANAGEMENT CAVEATS

The following observations are intended to assist with the practical application of the information presented in this paper:

- Recommended management variability (RMV) includes a range of values within reference variability that implies a high degree of resilience and sustainability for the ecosystem. RMVs most often describe mid-range values under the assumption that the extremes should be rare and will occasionally exist whether or not there is a deliberate attempt to create or maintain them.

- Allowing indicators to routinely exist at extremes, or outside the range of variability, probably decreases ecosystem resilience and sustainability in most cases. In rare cases such as the realized expectation indicator, values at the extreme can be very desirable.

- The need for management action (management opportunity) is indicated by a difference between existing condition and RMV.

- Part of the variation within reference variability is random (e.g., mortality is influenced by weather pattern during a particular fire event), and part is systematic (e.g., species composition is influenced by aspect and elevation). Deciding where to operate within RMV therefore requires a knowledge of the physical and biological landscape as well as the cultural/social context in which management decisions are made.

- Sustainability of range-wide grove attributes is not necessarily dependent on sustainability of individual grove attributes (e.g., it may be acceptable, or even desirable, for one grove to be deficit in an attribute if another grove is surplus). In fact, for certain attributes this is very much the way things work in nature. Not all giant sequoia groves are going to have trees as large as the General Sherman tree. Therefore, any proposal to correct the difference between RMV and existing conditions in a specific grove should consider whether or not it is important to take into account the existing conditions in all the other groves. For example, it may be desirable to maintain a surplus of giant sequoia trees (a greater number than RMV) of a given size class in one grove to make up for a deficit somewhere else. On the other hand, because of the administratively derived protection goal, a surplus of fuels should rarely, if ever, be tolerated in any grove.

- In the social dimension be wary of the interpretation of the "limit of acceptable change". Regardless of scientific validity, diverse values and cultural inertia will allow change to happen only so fast. As Gifford Pinchot (1946) once said: "Find out in advance what the public will stand for. If it is right and they won't stand for it, postpone action and educate them."

- The concept of ecosystem management is new and some of the scientific information requires verification. Therefore, in the application of RMVs developed in this paper, common sense in relation to known science and site-specific conditions should prevail.

- Environmental analysis as required by NEPA is always required for project implementation, regardless of collaborative agreements or other processes prior to developing a project proposal.

CONCLUDING COMMENTS

The key ecological elements, environmental indicators, and the quantification of indicators presented in this paper must be subject to frequent review and revalidation. Specific areas that should be reviewed in the very near future are:

- refining ecological influence zone designation criteria for all national forest giant sequoia groves;

- characterizing forest dynamics in terms of rate of fuel accumulation and structural changes over time;
- refining the vegetation mosaic indicators in light of site specific inventory data currently being collected for a number of national forest giant sequoia groves (e.g., Deer Creek, Converse Basin);
- visualizing the physical arrangements of gaps, patches, and seral stages through computer modeling (e.g., Bonnicksen 1993a, b) or other means;
- refining social indicators where there is no existing quantitative data; and
- refining and ground-truthing the draft Shulman and Gelobter (1996) fire risk assessment.

Members of the Giant Sequoia Ecology Cooperative (USDA 1996) should be an integral part of this adaptive management process.

Not seeing the forest for the trees has been a common expression in forestry. We have observed through this work that our past and present efforts to classify vegetation and ecosystems often masks our view of the finer scale of diversity that exists within these types.

We have also learned through this work process that the restoration and maintenance of healthy forest ecosystems cannot simply focus on process. Rather, an understanding of structure and process at both the landscape (coarse) and plant aggregation (fine) scales is essential.

CHAPTER 7

Annotated Bibliography -- A Scientific Foundation

Many scientific and professional papers have been written on the subject of giant sequoia. This literature was interpreted and analyzed to seek an ecological foundation for ecosystem management of national forest giant sequoia groves and to help people understand the giant sequoia literature. Numerous articles from both the scientific and professional literature on giant sequoia are listed alphabetically here. Most of the citations are followed by a short summary.

- Agee, J.K.; Wakimoto, R.H.; Biswell, H.H. 1978. **Fire and fuel dynamics of Sierra Nevada conifers**. Forest Ecology and Management 1: 255-265.
  Content: A report on the role of natural fire as a regulator of fuel loading.
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: The lack of fire in many areas in the Sierra Nevada has led to the accumulation of dead material, causing an unprecedented buildup of surface fuels.
- Akers, J.P. 1986. **Ground water in the Long Meadow area and its relation with that in the General Sherman area, Sequoia National Park, California**. Water-resources Investigations Report 85-4178. Sacramento, CA: Geological Survey U.S. Department of the Interior; 15 p.
  Content: The movement of groundwater from the Long Meadow area to the General Sherman tree area within Sequoia National Park was investigated.
  Applicable to: The water ecosystem element.
  Critical Findings: Akers reports that:
  - Westward movement of groundwater from Long Meadow to the Sherman tree area is prevented by an eastward hydraulic gradient and low fracture permeability of a granodiorite ridge separating the two areas.
  - A dependable groundwater supply of 50 gallons per minute (72,000 gallons per day) can be developed from the Long Meadow area. This should not affect the ground or surface water in the General Sherman tree area.
- Anderson, R. Scott. 1994. **Paleohistory of a giant sequoia grove: the record from Log Meadow, Sequoia National Park**. In: Aune, P.S., technical coordinator. Proceedings of the symposium on giant sequoias: their place in the ecosystem and society; 1992 June 23-25; Visalia, CA. Gen. Tech. Rep. PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 49-55.
  Content: A study of pollen and plant macrofossils from Log Meadow in the Giant Forest Grove of Sequoia National Park.
  Applicable to: Climate ecosystem element.
  Critical Findings: The authors conclude that: "A return to a cooler or wetter climatic regime or both during the middle to late Holocene allowed the

expansion of the tree [giant sequoia], and the establishment of the modern grove."

- Anderson, M.A., Graham, R.C.; Alyanakian, G.J.; Martynn, D.Z. 1995. **Late summer water status of soils and weathered bedrock in a giant sequoia grove**. Soil Science 160(6): 415-422.
  Content: The study measured the late summer water status of regolith (soil + weathered bedrock) profiles in the Packsaddle Grove on the Sequoia National Forest to assess the distribution of available water by geomorphic position at the end of the dry season.
  Applicable to: Water ecosystem element.
  Critical Findings: "Overall, water potential decreases (becomes more negative) at any given depth as one moves upslope out of the drainage area... During consecutive years of drought, the greater moisture stress on upland sites, compared with drainages, becomes even more acute and may be an important factor in determining site suitability for giant sequoia."
- Aune, P.S. 1992. **Giant sequoias: their place in the ecosystem and society**. In: Proceedings of the symposium on giant sequoias (Sequoiadendron giganteum), their place in the ecosystem and society; 1992 June 23-25; Visalia, CA. Gen. Tech. Rep. PSW-GTR-151. Forest Service, U.S. Department of Agriculture; Pacific Southwest Station; 170 p.
  Content: Proceedings of the June 23-25, 1992 symposium held in Visalia, California.
  Applicable to: All aspects of ecosystem management of giant sequoia groves.
  Critical Findings: The proceedings contain 28 papers presented at the symposium. The objective of the symposium was to provide the state of knowledge on giant sequoia by blending the results of research with human values and perceptions while reviewing agency policies and management directions. Refer to the proceedings.
- Bancroft L.; Nichols, T.; Parsons, D.; Graber, D; Evison, B; van Wagtendonk, J. 1983. **Evolution of the natural fire management program at Sequoia and Kings Canyon National Parks**. A paper presented at the Wilderness Fire symposium; 1983 November 15-18.
  Content: A discussion of the Sequoia and Kings Canyon National Parks natural fire management program, the oldest of its kind in the United States.
  Applicable to: Fire, organic debris, and vegetation ecosystem elements.
  Critical Findings: Fire as a natural process is important to the long-term preservation of natural ecosystems.
- Bates, T.R. 1998. **Response of young-growth giant sequoia to management strategies**. Berkeley: University of California; 94 p. Master's thesis.
  Content: This thesis describes the establishment of a long-term study in Mountain Home State Forest to investigate: how giant sequoia responds to understory burning in spring vs. fall; how intensity of underburning affects the growth of giant sequoia; how thinning and understory burning affect the regeneration of giant sequoia; how the use of thinning and understory burning affect other vegetation in giant sequoia groves. The study was started in 1989 with remeasurement of the established permanent plots is planned to be every

10 years. This thesis reports the first 5-year results (i.e., 1994) of this long-term study

Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: The following results are documented based on the five year measurements (i.e., 1994): trees in treated plots annually grew three times more in diameter than trees in corresponding control plots. Trees in the thinning-only and thinning-and-underburning plots grew an average of 0.34 inches in diameter per year compared to 0.12 inches per year in the control plots. Preliminary height growth data suggests that giant sequoia trees in the treated plots will grow an average of 1.5 feet per year as compared to 0.9 feet per year for trees in the untreated control plots.

- Biswell, H.H. 1961. **The big trees and fire**. National Parks Magazine (April issue) 35: 11-14.
  Content: The role of fire in giant sequoia groves is discussed.
  Applicable to: Fire, organic debris, and vegetation ecosystem elements.
  Critical Findings: This is an early report by Dr. Biswell, a pioneer in fire ecology research in giant sequoia-mixed conifer groves.
- Biswell, H. 1975. **Placer county big tree grove.** National Parks and Conservation: 14-17.
  Content: A report on the most northerly giant sequoia grove.
  Applicable to: Vegetation mosaic ecosystem element.
  Critical Findings: This report describes the history and ecology of the Placer giant sequoia grove. Dr. Biswell documents the concern of Dr. Libby, Professor Emeritus of genetics, "... the intent of perpetuating the grove by this means [i.e., planting giant sequoia seedlings] is commendable, but if this stand is a distinct ecological race of giant sequoia--as it might be--its future scientific and practical value will be destroyed eventually by the introduction of non-natives to the grove."
- Bonnicksen, T.M.; Stone, Edward C. 1978. **An analysis of vegetation management to restore the structure and function of presettlement giant sequoia-mixed conifer forest mosaics**. Unpublished final report to the USDI National Park Service, Sequoia and Kings Canyon National Parks, California.
  Content: The structural properties of the presettlement giant sequoia-mixed conifer forest in the Redwood Creek watershed of Sequoia and Kings Canyon National Parks were characterized (i.e., quantified) and compared to what existed in 1977 when the study was conducted. This report is based on Tom Bonnicksen's Ph.D. Dissertation completed at the University of California, Berkeley.
  Applicable to: Fire and vegetation mosaic ecosystem elements.
  Critical Findings: It was determined, for example, that: 1) the Redwood Canyon watershed is comprised of a mosaic of aggregations as space-time systems with most of the aggregations ranging from 135 to 1600 square meters (0.03 to 0.395 acres) with most overstory aggregations generally less than 800 square meters (0.20 acres); 2) conifer dominated aggregations have increased from what was present in the presettlement forest; 3) white fir top tier dominated aggregations increased from comprising 27.4 of the watershed in

1890 to 36.7 percent in 1977; 4) hardwood aggregations have decreased from comprising 9.6 percent of the watershed in 1890 to 6.3 percent in 1977; 5) shrub dominated aggregations have decreased from comprising 19 percent of the watershed in 1890 to 10.9 percent in 1977; 6) bare soil gap areas decreased from comprising 7.5 percent of the watershed area to 5.1 percent in 1977; 7) white fir dominated 45.5 percent of the watershed area covered by sapling and seedling aggregations in the 1890 presettlement forest; 8) the presettlement forest continued mature tree aggregations of which 74 percent contained an understory of trees and shrubs disputing the claim that presettlement forest was mostly open and park-like.

- Bonnicksen, Thomas M.; Stone, Edward C. 1981. **The giant sequoia-mixed conifer forest community characterized through pattern analysis as a mosaic of aggregations**. Forest Ecology and Management 3(1980/81): 307-328.
  Content: A study was conducted in the Redwood Creek watershed in Sequoia and Kings Canyon National Parks. This paper formally publishes some of the results presented in Bonnicksen and Stone (1978).
  Applicable to: Fire and vegetation mosaic ecosystem elements.
  Critical Findings: The giant sequoia-mixed conifer forest community in the Redwood Creek watershed is composed of mosaics of more or less even-aged aggregations that are maintained by a process of cyclic change.
- Bonnicksen, Thomas M.; Stone, Edward C. 1982a. **Reconstruction of a presettlement giant sequoia-mixed conifer forest community using the aggregation approach**. Ecology 63(4): 1134-1148.
  Content: The presettlement state (i.e., the ancient forest as it appeared before 1890) of a giant sequoia-mixed conifer forest community in the Redwood Creek watershed of Sequoia and Kings Canyon National Parks is reconstructed using a backward projection in time of plant aggregations. This paper formally publishes some of the results presented in Bonnicksen and Stone (1978).
  Applicable to: Fire and vegetation mosaic ecosystem elements.
  Critical Findings: Several major findings that are important to our overall understanding of presettlement (i.e., before 1890) vegetation mosaic in giant sequoia groves: 1) most of the overstory aggregations covered an area of 800 square meters (0.197 acres) indicating that the forest community is a mosaic of predominantly small but relatively distinct aggregations composed of one or more layers each layer made up of trees of about the same age; 2) there has been a general increase in the area of aggregations dominated by pole size and mature trees and a corresponding decrease in the area of aggregation dominated by sapling and seedling-size trees i.e., saplings and seedlings as the top tier of vegetation covered 28 percent (over one-fourth) of the watershed in 1890 as compared to 9 percent in 1977; 3) the proportion of the Redwood Creek watershed occupied overstory aggregations was 49 percent in 1890 as contrasted to 63 percent in 1977; 4) overstory aggregation areas comprised of white fir increased from 27 percent in 1890 to 37 percent in 1977; 5) area comprised of mostly hardwoods was higher in 1890 (10 percent) as compared to 6 percent in 1977; 6) area of Redwood Creek watershed comprised of shrubs has decreased from 19 percent in 1890 to 11 percent in 1977; and 7) 74 percent of the watershed

in 1890 was comprised of large mature-and mature-tree aggregations containing an understory of trees and/or shrubs. 8) Bonnicksen and Stone conclude that our view of giant sequoia mixed conifer forests in presettlement times as being largely open and park-like is incorrect. Understory trees and shrubs occupied a large area of the mature upper tier classified presettlement forest.

- Bonnicksen T.M.; Stone, Edward C. 1982b. **Managing vegetation within U.S. national parks: a policy analysis**. Environmental Management 6(2): 101-102.
  Content: A paper addressing the need to develop quantitative, clear objectives to restore national park ecosystems to their presettlement or natural state.
  Applicable to: Ecosystem management, adaptive management, reference variability.
  Critical Findings: Bonnicksen and Stone state: "No matter which philosophy is accepted, national park ecosystems will forever more be the product of man's actions, and man's flawed knowledge of what constitutes their natural structure and function. To be honest with themselves and the public, scientists and Park Service managers must put aside their differences, decide on the goal, and act on what is learned from scientific investigations. They must always be open to change as knowledge grows and new insights are reported."
- Bonnicksen, T.M.; Stone, E.C. 1985. **Restoring naturalness to national parks**. Environmental Management 9(6): 479-486.
  Content: A paper addressing the need to recover as much remaining ecological information as possible to serve as a basis for developing quantitative standards to restore naturalness in national parks.
  Applicable to: Ecosystem management, reference variability.
  Critical Findings: Physical evidence needed to develop quantitative standards of naturalness is rapidly disappearing because of the effects of wildfires, decomposition, successional changes, and other disturbances. A "rescue ecology" program is recommended to recover as much ecological information as possible before it is lost.
- Bonnicksen, Thomas M. 1988. **Standards of naturalness: the national parks management challenge**. Landscape Architecture 78(2): 134 and 120.
  Content: A paper addressing the need to develop "standards of naturalness" which in turn would serve as a basis of management for any national park in the world.
  Applicable to: Ecosystem management, reference variability.
  Critical Findings: Bonnicksen states that quantitative standards of naturalness are essential for guiding ecological restoration projects in national parks throughout the world.
- Bonnicksen, Thomas M. 1993a. **Restoring ancient giant sequoia forests**. An electronic publication. Department of Forest Science; College Station: Texas A&M University.
  Content: A computer generated recreation of Redwood Mountain Grove in 1875.
  Applicable to: Vegetation mosaic ecosystem element.
  Critical Findings: A three dimensional visualization of change in a giant sequoia ecosystem caused by disturbance events, (e.g., fire).

• Bonnicksen, Thomas M. 1993b. **Ancient forests of the Sierra Nevada.** Unpublished speaker's notes for an industry sponsored economic summit.
Content: The future of ancient forests in the Sierra Nevada is discussed.
Applicable to: All key ecosystem elements.
Critical Findings: The author reports that:
• "Ironically, excluding people from nature is an unnatural change that will ultimately destroy the ecological communities that environmentalists wish to preserve."
• Ancient Sierra Nevada forests are comprised of aggregations (e.g., patches, gaps, even-aged groups of trees, etc.).
• The ancient forest mosaic changed continuously in both space and time.
• Major disturbance events (e.g., lightning, fire, insects, animal populations, disease, landslides, human activity) brought about this continuous change.
• Scientific evidence shows that Native American burning along with lightning played a decisive role in creating and maintaining ancient Sierra Nevada forests. The role of Native Americans as a natural force in the Sierras started at least 4,500 years ago.
• Bonnicksen concludes, "The results of our studies show that ancient forests that are supposed to be protected are actually disappearing at an alarming rate."
• Bonnicksen supports a sustainable old-growth option where people are part of nature.

• Buchanan, H.; Gibbens, R.P.; Biswell, H.H. 1966. **Checklist of higher plants of Whitaker's Forest**. Unpublished report to the National Science Foundation. School of Forestry, University of California, Berkeley. 41 p.
Content: A checklist of higher plants.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: A listing of higher plants known to occur in the Whitaker's Forest area is provided.

• Burns, Russell M.; Honkala, Barbara H., technical coordinators. 1990a. **Silvics of North America**. Volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture; 675 p.
Content: Silvical characteristics of major North American conifers.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: Refer to the Handbook.

• Burns, Russell M.; Honkala, Barbara H., technical coordinators. 1990b. **Silvics of North America**. Volume 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture; 877 p.
Content: Silvical characteristics of major North American hardwoods.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: Refer to the Handbook.

• Bush G. 1992. **Giant sequoia in national forests**. A proclamation by the President of the United States. 1992 July 14; 1 p.
Content: A proclamation by the President of the United States.
Applicable to: All aspects of ecosystem management of national forests giant sequoia groves.

Critical Findings: The proclamation extended the intent of the Sequoia National Forest Mediated Settlement Agreement to all national forest giant sequoia groves.

•Caprio, A.C.; Mutch, L.S.; Swetnam, T.W.; Baisan, C.H. 1994. **Temporal and spatial patterns of giant sequoia radial growth response to a high severity fire in A.D. 1297**. Unpublished contract report to the California Department of Forestry and Fire Protection, Mountain Home State Forest.
Content: The radial growth response of giant sequoia trees that survived the high severity fire in the year 1297 in Mountain Home State forest was examined.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Refer to article.

•Caprio, A.C.; Swetnam, T.W. 1995. **Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada, California**. In: Brown, J.K.; Mutch, R.W.; Spoon, C.W.; Wakimoto, R.H., technical coordinators. Proceedings of the symposium on fire in wilderness and park management; 1993 March 30-April 1; Missoula, MT. Gen. Tech. Rep. INT-GTR-320. Odgen, UT: Intermountain Research Station, Forest Service, U.S. Department of Agriculture; 173-79.
Content: Historic fire regimes.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Refer to article.

•Christensen, N.L.; Franklin, J.F. 1987. **Small-scale disturbance in forest ecosystems: meeting review**. Bulletin of the Ecological Society of America 68: 51-53.
Content: A discussion of the influence of small-scale disturbance events in forest ecosystems.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: A gap is defined as a site at which a canopy individual or individuals have died resulting in a change in the surviving community. Refer to the paper for further information.

•Cockrell, R.A.; Knudson, R.M.; Stangenberger, A.G. 1971. **Mechanical properties of southern Sierra old-and second-growth giant sequoia**. University of California, California Agricultural Experiment Station, Bulletin 854.
Content: A paper on wood strength properties of giant sequoia.
Applicable to: Organic debris and vegetation mosaic ecosystem elements.
Critical Findings: Refer to the paper.

•Davidson, J.G.N. 1972. **Pathological problems in redwood regeneration from seed**. Berkeley: University of California. Ph.D. dissertation.
Content: A doctoral dissertation on the pathological problems of coast redwood regeneration developing from seed.
Applicable to: Vegetation mosaic ecosystem element and general knowledge.
Critical Findings: This report has indirect significance to potential pathological problems of giant sequoia regeneration. The controversy over the scientific name for giant sequoia is discussed.

- Davis F.W.; Stoms, D.M. 1996. **Sierran vegetation: a gap analysis.** In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chap. 23. Davis, CA: University of California, Centers for Water and Wildland Resources.
  Content: A gap analysis of plant community types for the Sierra Nevada region.
  Applicable to: Vegetation mosaic and fire ecosystem elements.
  Critical Findings: Refer to the report.
- Demetry, Athena; Duriscoe, Daniel M. 1996. **Fire-caused canopy gaps as a model for the ecological restoration of giant forest village.** Unpublished report to Sequoia and Kings Canyon National Parks, National Park Service, USDI.
  Content: A publication documenting the results of a study of fire-caused gaps as a model of ecological restoration of giant forest village in Sequoia and Kings Canyon National Park. Vegetation response was analyzed in 18 gaps of three different sizes that developed within the last 7 to 15 years:
  1) small gaps from 0.067 hectares (0.16 acres) to 0.097 hectares (0.239 acres) with a mean of 0.086 hectares (0.212 acres); 2) medium gaps from 0.15 hectares (0.37 acres) to 0.24 hectares (0.59 acres) with a mean of 0.20 hectares (0.49 acres); and 3) large gaps from 0.34 hectares (0.839 acres) to 1.17 hectares (2.89 acres) with a mean of 0.67 hectares (1.65 acres).
  Applicable to: Fire and vegetation mosaic ecosystem elements.
  Critical Findings: The authors report that:
  - large gaps (1.65 acres) contained the greatest number of tree species, followed by medium (0.49 acre) and small (0.21 acre) gaps.
  - giant sequoia, sugar pine, and white fir were present in most gaps.
  - giant sequoia had the highest density of the tree species in all gap sizes.
  - ponderosa pine and incense-cedar were found mainly in the lower-elevation plots, and red fir in the higher elevation plots and north and northeast plots.
  - canyon live oak and black oak each occurred in only 2 of the 18 gaps examined.
  - 22 shrub species were present with the large gaps containing the greatest number of shrub species followed by medium and small gaps. Whitethorn, greenleaf manzanita, Sierra gooseberry, Sierra currant, bush chinquapin, creeping snowberry, and littleleaf ceanothus occurred in the majority of gaps studied. Mountain whitethorn, greenleaf manzanita, and Sierra gooseberry were commonly observed pioneer shrub species with significantly higher cover in large gaps.
  - giant sequoia seedlings were both more dense and taller in gap centers than at the edges, and that pioneer shrub species tended to have denser cover in gap centers than at the edges.
  - Demetry and Duriscoe conclude: "These results show that for many species, gap size can explain a significant amount of variability in tree density and shrub cover in gaps. Several species, those which have characteristics of pioneer species, grew significantly denser or covered significantly more area in large gaps. These pioneer species include giant sequoia, Jeffrey pine, whitethorn, greenleaf manzanita, Sierra gooseberry, bitter cherry, elderberry, and creeping snowberry. For these species, locally intense fire which kills at

least a 0.3 hectare patch of mature trees may be necessary for their vigorous growth or recruitment. The mechanism by which these species grow more densely and vigorously in large gaps may be a result both of the heating properties of fires which create large gaps, allowing more individuals to germinate (e.g., drying of the canopy-stored cones of giant sequoia and heat scarification of the soil seed bank, particularly for *Ceanothus* spp.), and of increased resource availability in large gaps allowing both higher survival and more rapid growth of seedling."

- Du, W.; Fins, L. 1989. **Genetic variation among five giant sequoia populations.** Silvae Genetica 38(2): 70-76.
  Content: Genetic variation of five giant sequoia populations from the southern part of the species range was evaluated.
  Applicable to: Vegetation mosaic ecosystem element.
  Critical Findings: Significant genetic variation in growth, crown form, cold hardiness, and patterns of cold acclimation was found among the five populations of giant sequoia.
- Dulitz, D.; Medina, J.; Lee, S. 1998. **Vegetation responses following three management strategies in a giant sequoia forest on Mountain Home Demonstration State Forest**. California Forestry Note No. 111. California Department of Forestry, Sacramento, CA; 13 p.
  Content: Vegetational changes were evaluated within a giant sequoia grove in Mountain Home State Forest comparing three management strategies: 1) preservation and protection; 2) selective timber harvesting of non-giant sequoia species; 3) prescribed burning.
  Applicable to: Vegetation mosaic reference variability
  Critical Findings: This study confirmed that the lack of disturbances in giant sequoia forests will result in formation of a fully stocked stand with little or no regeneration of any of the tree species. The most likely trees species to regenerate will be white fir, leading to a long term shift in species composition. Treating the forest with selective thinning or prescribed burning will result in giant sequoia regeneration immediately following the disturbance but high levels of seedling mortality can result as a function of site and climate variables. Irrespective of the high levels of seedling mortality, survival was considered adequate to insure establishment and recruitment of giant sequoia in the understory.
- Dunning, D.; Reineke, H. 1933. **Preliminary yield tables for second-growth stands in the California region**. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Technical Bulletin No. 354. 24 p.
  Content: Growth and yield tables for second-growth mixed conifer stands in California.
  Applicable to: Vegetation mosaic ecosystem element.
  Critical Findings: Stand conditions (e.g., tree attributes, density, volume per acre) are described by age and site class.
- Eaton, J. 1996. **Personal communication**. Retired District Fuels Specialist, Hot Springs Ranger District, Sequoia National Forest, Hot Springs, CA.
  Content: A discussion between Mr. Jack Eaton and Mr. Bob Rogers.

Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: This discussion focused on identifying giant sequoia grove areas at risk of catastrophic fire occurrence because of a number of interconnected factors (e.g., fuel loading, fuel ladders, dense vegetation, topographic considerations).

•Elliott-Fisk, D.; Stephens, S.; Aubert, J.E.; Murphy, D.; Schaber, J. 1996. **Mediated Settlement Agreement for Sequoia National Forest, Section B, giant sequoia groves: an evaluation**. In: Sierra Nevada Ecosystem Project: Final report to Congress, Addendum. Davis, CA: University of California, Centers for Water and Wildland Resources.
Content: An evaluation of giant sequoia groves under the Mediated Settlement Agreement.
Applicable to: All identified ecosystem elements important to the management of giant sequoia groves and surrounding areas.
Critical Findings: The report includes:
• an ecological database, geographic information system with spatial grove boundaries, and scientific bibliography;
• an assessment of current grove mapping methodologies used by Sequoia National Forest and by other administrative units;
• an evaluation of the MSA;
• a review of grove management practices and responses to these practices;
• a review of the implications of the Sequoia National Forest moving towards implementation of ecosystem management of national forest giant sequoia groves.
• a review of past and present human uses of the groves, human values, and various methods of potential public information, dissemination, and education.

•Engbeck, J.H. 1976. **The enduring giants**. Regents of the University of California, University Extension, Berkeley. 120 p.
Content: An interpretive guide with a focus on Calaveras Big Trees State Park.
Applicable to: All ecosystem elements.
Critical Findings: The natural history of giant sequoia, history of human association with giant sequoia, and the movement to preserve Calaveras Groves are discussed.

•Erman, D.C.; Jones, R. 1996. **Fire frequency analysis of Sierra forests**. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chap. 42. Davis, CA: University of California, Centers for Water and Wildland Resources.
Content: The pattern and frequency of fire size reported for seven national forests and Sequoia-Kings Canyon National Parks were assessed by frequency analysis.
Applicable to: Fire and organic debris ecosystem elements.
Critical Findings: The following conclusions were reached.
• The forests in the different Sierra regions do not have similar fire size at the same frequencies;
• The fire frequencies have changed over time for most but not all forests in this century.

• The magnitude of change in fire frequencies among the forests depends on the forest. Those in the central-western Sierra showed the greatest change.
• Not all forest exhibit a similar pattern of fire frequency.
• There is a regional pattern in fire frequency. The trend in the central-western Sierra, particularly the Eldorado National Forest, is for small, frequent fires to be smaller since 1950 and large, infrequent fires to be larger. A nearly opposite pattern occurs in the southern Sierra, particularly Sequoia-Kings Canyon National Parks.

• Eyre, F.H. (ed.). 1980. **Forest cover types of the United States and Canada**. Society of American Foresters. Washington DC. 148 p.
Content: A classification of major forest types found in the United States and Canada based on existing, dominant overstory vegetation.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: SAF Forest Cover types that have been reported within or near giant sequoia groves include: Sierra Nevada Mixed Conifer (243), Red Fir (207), White Fir (211), Pacific Ponderosa Pine-Douglas Fir (244), Pacific Ponderosa Pine (245), California Black Oak (246), riparian woodland, meadows and rock outcrops.

• Fins, L. 1981. **Seed germination of giant sequoia**. Tree Planters Notes. Forest Service, U.S. Department of Agriculture; 3-8.
Content: A report documenting the results of a giant sequoia seed germination trial.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: The author states: "Germination trials with giant sequoia seed samples show that long stratification periods ($\geq$ 60 days) and an overnight soak in distilled water prior to stratification promote rapid germination at relatively high rates."

• Fins, L.; Libby, W.J. 1982. **Population variation in *Sequoiadendron*: seed and seedling studies, vegetative propagation, and isozyme variation**. Silvae Genetica 31(4): 102-110.
Content: This paper is the first published study of patterns and amounts of genetic variation among samples from native populations of giant sequoia.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: "Seed samples were collected from 35 natural populations of giant sequoia and examined for seed weight, germination, cotyledon number, rootability of cuttings, and isozyme variation. Samples were significantly variable in percent seed germination, cotyledon number, isozyme allele frequencies, and observed heterozygosity... Little if any recent gene flow is likely to have occurred between the northern and southern populations. Relatively low heterozygosity among embryo samples suggests that inbreeding and/or population substructuring is likely in giant sequoia populations. Relatively higher levels of heterozygosity are found in the southern parts of the range, suggesting different local selective regimes...Careful attention to these patterns will allow us to match populations, families, or clones to appropriate growing sites, and will accelerate our progress toward the domestication and proliferation of this potentially useful California endemic."

•Fins, L.; Libby, W.J. 1994. **Genetics of giant sequoia**. In: Aune, Phil, technical coordinator. Proceedings of the symposium on giant sequoias: their place in the ecosystem and society; 1992 June 23-25; Visalia, CA. Gen. Tech. Rep. PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 65-68.
Content: Natural patterns of genetic variation of giant sequoia are discussed.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: There is a small to modest amount of genetic variation among populations of giant sequoia with some north to south trends evident. Natural regeneration is recommended but where planting is necessary, the authors recommend that seeds from at least 20 different trees from the part of the grove where planting is to occur should be used for the planting stock. The authors conclude: "...we have a responsibility not only to maintain the genetic health of our native groves, but to maintain their genetic integrity as well."

•Flint, W.E. 1987. **To find the biggest tree**. Sequoia Natural History Association, Inc. Three Rivers, CA. 116 p.
Content: A booklet documenting the authors search over a 40 year period to find the largest giant sequoia trees.
Applicable to: Reference variability.
Critical Findings: Data is provided of the authors measurements of large giant sequoia trees in a number of groves throughout the Sierra Nevadas. The General Sherman tree is listed as being the largest tree in the world with a height of 274.9 feet, a diameter breast height of 25.1 feet, a ground perimeter measurement of 102.6 feet, and a total volume (ignoring burns) of 52,508 cubic feet.

•Franklin, J.F.; Fites-Kaufmann, Jo Ann. 1996. **Assessment of late-successional forests of the Sierra Nevada**. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chap. 21. Davis, CA: University of California, Centers for Water and Wildland Resources.
Content: An assessment of late-successional, including old-growth forest conditions for the Sierra Nevada.
Applicable to: Vegetation mosaic ecosystem element, patch and gap frequency indicator, plant community indicator.
Critical findings: Several major findings were reported on the condition of late successional forests in the Sierra Nevadas.

•Fry, W. 1933. **The giant sequoia avalanche**. Sierra Club Bulletin 18(1): 118-120.
Content: A description of the greatest-known avalanche in the southern Sierra which occurred on December 20, 1867 on the north side of Dennison Mountain.
Applicable to: All ecosystem elements.
Critical Findings: It is estimated that the avalanche reduced the original Garfield Big Tree Grove area by about one-third. Refer to the article for further details.

•Fry W.; White, J.R. 1948. **Big trees**. Revised enlarged edition. Palo Alto: Stanford University Press; 126 p.
Content: An early report on giant sequoia groves in California.
Applicable to: All ecosystem elements.

Critical Findings: Fry and White provide a list of giant sequoia groves. They provide descriptive remarks for each of the groves they list. Refer to the section titled The California Big Tree groves on pages 109-126.

•Fullmer, D.G.; Rogers, R.R.; Manley, J.D.; Stephenson, L.L. 1996. **Restoration as a component of ecosystem management for giant sequoia groves in California**. In: Pearson, D.L., Klimas C.V., editors. Proceedings of the Society for Ecological Restoration conference, The role of restoration in ecosystem management; 1995 September 14-16; Seattle, WA. Society of Ecological Restoration, Madison, WI, 109-115.
Content: A paper on restoration of national forest giant sequoia groves.
Applicable to: All aspects of ecosystem management.
Critical Findings: Risk of extreme wildfire was lower in pre-Euroamerican settlement giant sequoia ecosystems. Refer to the paper.

•Gebauer, S.B. 1992. **Changes in soil properties along a post-fire chronosequence in a sequoia-mixed conifer forest in Sequoia National Park, California**. Durham, North Carolina: Duke University; 92 p. Master's thesis.
Content: A soil property study in Sequoia National Park.
Applicable to: Soil productivity, organic debris, fire ecosystem elements.
Critical Findings: Refer to thesis.

•Gordon J.C. 1993. **Ecosystem management**: **an idiosyncratic overview**. In: Aplet, H., N. Johnson, J.T. Olson, and V. Alaric Sample. Defining Sustainable Forestry. The Wilderness Society. Island Press. 240-245.
Content: An overview of ecosystem management.
Applicable to: All aspects of the ecosystem management process.
Critical Findings: Gordon states:
• "To succeed as a tool for managing complex systems, ecosystem management must be describable in a way that can be broadly and readily understood."
• Gordon described five simple descriptors for ecosystem management: 1) manage where you are; 2) manage with people in mind; 3) manage across boundaries; 4) manage based on mechanisms rather on algorithms (rules of thumb); and 5) manage without externalities.

•Graumlich L.J. 1993. **A 1000-year record of temperature and precipitation in the Sierra Nevada**. Quaternary Research 39: 249-255.
Content: Tree-ring data from subalpine conifers in the southern Nevada were used to reconstruct temperature and precipitation back to A.D. 800.
Applicable to: Atmospheric hierarchy and all ecosystem elements such as vegetation mosaic that are affected by climate fluctuations.
Critical Findings: The author states: "The long-term record presented here indicates that the 20th century is anomalous with respect to precipitation variation. A tabulation of 20- and 50-yr. means indicates that precipitation equaling or exceeding 20th-century levels occurred infrequently in the 1000 +- yr. record." The author also states: "These results suggest that drought in California is not an anomaly when considered in a long-term context and that agricultural, industrial, and urban systems that are dependent on water resources are highly vulnerable to disruption."

•Guldin J.M. 1991. **Uneven-aged Bdq regulation of Sierra Nevada conifers.** Western Journal of Forestry 6(2): 27-32.
Content: Implementing uneven-age management (i.e., the selection system) in Sierra Nevada mixed conifer stands.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: An uneven-age management regulation scheme (i.e., Bdq approach) is proposed as a method to insure sustainability of Sierra Nevada mixed conifer stands.

•Haase, Sally M.; Sackett, Stephen S. 1998. **Effects of prescribed fire in giant sequoia-mixed conifer stands in Sequoia and Kings Canyon National Parks.** In: Pruden, Teresa L.; Brennan, Leonard A., technical coordinators. Proceedings of the 20th Tall Timbers Fire Ecology Conference, Fire in Ecosystem Management: Shifting the Paradigm from Suppression to Prescription; 1996 May 7-10; Boise, ID. Tallahassee, FL: Tall Timbers Research Station; 236-243.
Content: A study on the effects of management-ignited prescribed fires.
Applicable to: Organic debris and ecosystem elements.
Critical Findings: Findings show that instantaneous lethal temperatures (150 degrees F [6 degrees C]) can be reached in the soil and within the cambium of giant sequoia and sugar pine trees during prescribed burning operations. Some mortality of sugar pine trees occurred.

•Halpin, Pat. 1995. **A cross-scale analysis of environmental gradients and forest pattern in the grant sequoia-mixed conifer forest of the Sierra Nevada.** University of Virginia; 277 pages. Ph.D. dissertation.
Content: The most detailed hydrological study completed to date at the microsite level in giant sequoia groves.
Applicable to: Water ecosystem element.
Critical Findings: Refer to the dissertation.

•Hammon, Jensen, and Wallen. 1964, 1970, 1975, 1976. **Sequoia tree inventory.** Hammon, Jensen, and Wallen Mapping and Forestry Service, Oakland, CA. An unpublished report to the USDI National Park Service, Sequoia and Kings Canyon National Parks, Three Rivers, CA.
Content: A 100 percent inventory of giant sequoia trees conducted between 1964 and 1976 in Sequoia and Kings Canyon National Parks.
Applicable to: Vegetation mosaic, fire and organic debris ecosystem elements.
Critical Findings: A 160,911 giant sequoia trees in 35 giant sequoia groves were inventoried. This data base is the basis for the research papers by Stohlgren (1991, 1992, 1993a, 1993b).

•Hartesveldt, R.J. 1962. **The effects of human impact upon Sequoia gigantea and its environment in the Mariposa Grove, Yosemite National Park, California.** Ann Arbor, University of Michigan; 310 p. Ph.D. dissertation.
Content: A study to determine the influence of human activities on giant sequoia trees and their environment.
Applicable to: All ecosystem elements.
Critical Findings: Refer to the dissertation.

•Hartesveldt, R.J.; Harvey, H.T. 1967. **The fire ecology of sequoia regeneration.** Proc. Tall Timbers Fire Ecol. Conf. 7:65-77.

Content: A study of regeneration following fire.
Applicable to: The organic debris, fire, and vegetation mosaic ecosystem elements.
Critical Findings: Refer to the article.

• Hartesveldt, R.J.; Harvey, H.T.; Shellhammer, H.S.; Stecker, R.E. 1975. **The giant sequoia of the Sierra Nevada**. U.S. Gov. Printing Office. Washington, DC.
Content: A summary of knowledge regarding the giant sequoias in the Sierra Nevadas.
Applicable to: All key ecosystem elements.
Critical Findings: Refer to the report.

• Harvey, H. Thomas; Shellhammer, H.S.; Stecker, R.E. 1980. **Giant sequoia ecology, fire and reproduction**. USDI National Park Service, Scientific Monograph Series No. 12. Washington, DC.
Content: A monograph documenting numerous scientific studies largely conducted in Sequoia and Kings Canyon National Parks between 1964 and 1975.
Applicable to: Various ecosystem elements with specific information provided on the fire, organic debris, animal species, and vegetation mosaic ecosystem elements.
Critical Findings: The results of several studies are reported on: environmental factors; vegetation changes following fire; ; giant sequoia reproduction, survival and growth; arthropods associated with giant sequoia; the role of insects in giant sequoia reproduction; bird, mammals, fires and giant sequoia reproduction; Douglas squirrels and sequoia reproduction.

• Harvey H.T.; Shellhammer, H.S. 1991. **Survivorship and growth of giant sequoia *Sequoiadendron giganteum* [Lindl.] Buchh.) seedlings after fire**. Madrono 38(1): 14-20.
Content: a 20-year study of the efficacy of fire in promoting reproduction and growth of giant sequoia.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: The authors report:
• There was no significant relationship between the starting density of giant sequoia seedlings and the average annual survival rate or the proportion surviving in 1986.
• Difference in giant sequoia seedling survival were due to differences in substrate and not to density dependent effects.
• Survival and growth of giant sequoia seedlings on burn piles was significantly greater than other substrates.
• Height growth of giant sequoia seedlings was significantly greater on burn pile substrates than on other substrates.
• Most of the burn piles were placed away from the canopy of nearby giant sequoias to reduce potential damage to trees, hence seedlings growing on the burn piles received considerable light.
• A number of environmental interactions seem to be affecting survival rates such as: soil wettability and friability of heated soils; mortality of seeds and competing species; mortality of microorganisms/pathogens in heated soil;

rising heat opens the serotinus giant sequoia cones causing abundant seed fall; and desirable soil moisture conditions to name but a few.

- Holland, R. 1986. **Preliminary descriptions of the terrestrial natural communities of California**. Unpublished mimeo available from the California Department of Fish and Game, Sacramento, CA.
  Content: Terrestrial natural communities of California are described.
  Applicable to: Vegetation mosaic ecosystem element.
  Critical Findings: Refer to paper and to Keeler-Wolf (1989).
- Holling C.S. 1992. **Cross-scale morphology, geometry, and dynamics of ecosystems**. Ecological Monographs 62(4): 447-502.
  Content: Two major propositions are tested in this paper: 1) that a small set of plant, animal, and abiotic processes structure ecosystems across scales in time and space; and 2) key structuring processes generate a discontinuous distribution of spatial structures coupled with discontinuous frequencies. Direction is provided for the development of programs to evaluate, monitor, and predict ecosystem and community changes across scales.
  Applicable to: Keystone ecosystem elements.
  Critical Findings: Four principal conclusions are reached: 1) the landscape is structured hierarchically by a small number of structuring processes into a small number of levels, each characterized by a distinct scale of "architectural" texture and of temporal speed of variables; 2) each of the small number of processes that influence structure does so over limited scale ranges. The temporal and architectural structure of ecosystem quanta are determined by three broad groups of processes, each dominating over different ranges of scale; 3) Because of the non-linear nature of mesoscale disturbance processes, fine-scale knowledge of autecology cannot simply be aggregated to represent behavior at scales beyond the scale of a patch or gap; 4) Behavioral and morphological attributes of animals can be used as a bioassay of existing landscape structure or a predictor of the impacts of changes in vegetation pattern on animal community structure. Refer to the monograph for a complete description of these findings..
- Hughes M.K.; Richards, B.J.; Swetnam, T.W.; Baisan, C.H. 1990. **Can a climate record be extracted from giant sequoia tree rings**. In: Betancourt, J.L.; MacKay, A.M., technical coordinators. Proceedings of the sixth annual Pacific climate (PACLIM) workshop; 1989 March 5-8; Asilomar, CA. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 23; 111-114.
  Content: A dendrochronological report focused on giant sequoia.
  Applicable to: All ecosystem elements with specific emphasis on the fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: The authors state: "There is a climate record to be extracted from the growth rings of giant sequoia. Rather than acting as a continuous recorder of precipitation or temperature, the rings act as event recorders for a class of extreme conditions, viz. severe drought. Is there anything unusual about the twentieth century in this record? Restricting the comparison to the last 500 years until a better replicated giant sequoia chronology exists for earlier

times, it would appear that frequency of droughts in the region centered on the mid-Sierra Nevada is greater than in the late nineteenth century, but similar to that in the 1500s and 1700s."

• Hughes M.K.; Brown, P.M. 1992. **Drought frequency in central California since 101 B.C. recorded in giant sequoia tree rings**. Climate Dynamics 6: 161-167.
Content: A report documenting the results of a study comparing August Palmer Drought Severity Indices for California State Climate Division (the San Joaquin basin) and low-growth events in giant sequoia chronologies from three sites, viz. Camp Six, Giant Forest, and Mountain Home.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: The authors state: "The period from roughly 1850 to 1950 had one of the lowest frequencies of drought of any 100 year period in the 2089 year record. The twentieth century so far has had a below-average frequency of extreme droughts."

• Huntington, E. 1914. **The climatic factor as illustrated in arid America**. The Carnegie Institute of Washington, Publication No. 192, Washington, DC.
Content: A study seeking to establish correlations between series of giant sequoia ring widths (i.e., annual rings were counted on 470 sequoia stumps) and meteorological records.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: Huntington noted "..it is the habit of the sequoia to grow in groups. Often-times half a dozen trees of the same age forming a circle. Frequently a tract of many acres is covered with trees of practically the same age."

• Kaplan-Henry, Terry A. 1995. **Channel function**. An unpublished technical report available from Sequoia National Forest, 900 West Grand Avenue, Porterville, CA.
Content: An unpublished technical report on stream morphology and sediment recommended management variability.
Applicable to: Stream morphology, sediment, and water ecosystem elements.
Critical Findings: Recommended management variability for vegetation bank stability, cutting, deposition, scouring and deposition, and percent stable material Pfankuch (1975) environmental indicators are listed and discussed for four channel groups (i.e., naturally stable, stable sensitive, unstable sensitive degraded, and naturally unstable). Each channel group contains a number of related Rosgen channel types.

• Keeler-Wolf, Todd. 1989. **An ecological survey of Moses Mountain candidate research natural area**. Sequoia National Forest, Tulare County, CA. An unpublished report to the USDA Forest Service, Sequoia National Forest, Porterville, CA.
Content: An ecological survey of the Moses Mountain area.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: A checklist of plant/tree species that occur in the Moses Mountain area.

•Keifer, M. 1995. **Changes in stand density, species composition, and fuel loading following prescribed fire in the southern Sierra Nevada mixed conifer type.** Supplement to the Bulletin of the Ecological Society of America 76: 138-139.
Content: A paper on the effects of prescribed fire.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Refer to paper.

•Keifer, MaryBeth. 1998. **Fuel load and tree density changes following prescribed fire in the giant sequoia-mixed conifer forest: the first 14 years of fire effects monitoring**. In: Pruden, Teresa L.; Brennan, Leonard A., technical coordinators. Proceedings of the 20th Tall Timbers Fire Ecology Conference, Fire in Ecosystem Management: Shifting the Paradigm from Suppression to Prescription; 1996 May 7-10; Boise, ID. Tallahassee, FL: Tall Timbers Research Station; 306-309.
Content: The short and long term effects of prescribed fire were examined.
Applicable to: Organic debris, fire, and vegetation mosaic ecosystem elements.
Critical Findings: The author reports:
• Immediately following prescribed fire in the giant sequoia-mixed conifer forest, the duff component was reduced by 93 percent, while woody fuels were reduced by 56 percent.
• In the 10 years following prescribed fire woody fuel nearly doubled. This increase was the result of the prescribed fire burning in dense stands, killing branches, and small understory trees.
• Total fuel load reached 75 percent of pre-fire levels after 10 years without fire.

•Kilgore, B.M. 1968. **Breeding bird populations in managed and unmanaged stands of *Sequoia gigantea*.** Berkeley: University of California; 187 p. Ph.D. dissertation.
Content: A study on breeding bird populations in managed and unmanaged giant sequoia stands.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Refer to the Ph.D. dissertation. Kilgore provides a list of 133 ground cover plant species occurring in Whitaker's Forest

•Kilgore, Bruce M. 1972a. **Fire's role in a sequoia forest**. Naturalist 23: 26-37.
Content: The natural role of fire in the giant sequoia-mixed conifer forest ecosystem is discussed.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Fire in the giant sequoia-mixed conifer forest:
• prepares a seedbed;
• cycles nutrients;
• sets back succession in certain relatively small areas;
• provides conditions which favor wildlife;
• provides a mosaic of age classes and vegetation types;
• reduces numbers of trees susceptible to attack by insects and disease;
• reduces fire hazards.

•Kilgore, B.M. 1972b. **Impact of prescribed burning on a sequoia-mixed conifer forest**. In: Proceedings of the Tall Timbers Fire Ecology conference; 1972 June 8-9; Tallahassee, FL, Tall Timbers Research Station.

Content: A paper reported at the 1972 Tall Timbers Fire Ecology conference reporting the impacts of prescribed burning on study plots in the Redwood Mountain Grove of Kings Canyon National park.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Prescribed fire caused mortality of 87 percent of white fir and sugar pine saplings and 38 percent of trees between 6 and 12 inches in the 5-acre experimental plot. Only one tree greater than 12 inches was killed by the prescribed burn. Litter and duff fuels were reduced from a preburn 50 tons/acre to 7.7 tons/acre following burning.

- Kilgore, B.M. 1973a. **The ecological role of fire in Sierran conifer forests: its application to National Park management**. Quarternary Research 3: 496-513.
  Content: The application of fire to national park management with an emphasis on Sequoia, Kings Canyon and Yosemite National Parks is discussed.
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: Kilgore states "Two or more burns in the same area over a period of years may be necessary to reduce understory vegetation and to make some openings in the crown canopy. Some sizable white fir may need to be cut and burned in certain high-value sequoia groves, or we may have to accept some fairly hot burning conditions to restore the system to what we believe were more natural environmental conditions. Once this is achieved, we would hope to perpetuate equilibrium conditions by allowing natural forces, including lightning fires to play their original role as nearly as possible."
- Kilgore, B.M. 1973b. **Impact of prescribed burning on a sequoia-mixed conifer forest**. In: Proceedings of the Tall Timbers Fire Ecology conference; 1972 June 8-9; Tallahassee, FL. Tall Timbers Research Station; 12: 345-375.
  Content: A report of a study investigating the impact of prescribed fire on certain biotic and abiotic elements in the Redwood Mountain Grove.
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: The 5-acre prescribed burn caused mortality to more than 87 percent of white fir and sugar pine saplings and 37 percent mortality of 6 to 12 inch DBH trees. Understory cover diminished significantly but the amount of understory light only increased slightly. Coverage and frequency of shrubs, grasses, and herbaceous plants were extremely low both before and after burning. Litter and duff fuels were reduced from a preburn level of 50 tons/acre to 7.7 tons/acre.
- Kilgore, Bruce M.; Biswell, H.H. 1971. **Sequoia germination following fire in a giant sequoia forest**. California Agriculture 25: 8-10.
  Content: A report on giant sequoia seed germination following fire.
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: The authors report that forest conditions have become more closed in many areas and shrubs and herbaceous plants are probably less abundant than in the past. Fire plays an important role in providing conditions suitable for germination, growth, and development of giant sequoia seedlings.
- Kilgore, B.M.; Sando, R.W. 1975. **Crown-fire potential in a sequoia forest after prescribed burning**. Forest Science 21: 83-87.

Content: A report on crown fire potential.
Applicable to: Fire and organic debris ecosystem elements.
Critical Findings: "Ladder fuels" capable of conducting fire into the crowns of mature trees have increased.

•Kilgore, Bruce M.; Taylor, D. 1979. **Fire history of a sequoia-mixed conifer forest.** Ecology 60(1): 129-142.
Content: Data on the years in which fires burned, on fire frequency, and on intensity and areal extent of fires were gathered from 935 fire scars on 220 stumps of mixed conifer species in an 1800 ha (4,446 acres) study area in the Bearskin, Tenmile, and Redwood Creek drainages of Sequoia National Forest and Sequoia and Kings Canyon National Parks.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: The following conclusions were reported:
• Fires of various sizes were found every 2 to 3 years somewhere in a given drainage (not necessarily the same site) and have documented a major decrease in fire scars after 1875 when Indian burning was eliminated and a complete absence after 1900.
• Frequent fire return interval suggests that the pre-1875 giant sequoia-mixed conifer forests did not usually have heavy accumulations of litter or dense thickets of understory trees.
• "...frequent fires would have led to an intricate mosaic of age classes and vegetation subtypes which, in turn, insured that a subsequent fire would not burn large areas with great intensity."
• Crown fires in the study area were absent for the past 400 to 2000 years.
• Native American caused fires augmented lightning caused fires to produce the fire return intervals Kilgore and Taylor observed prior to 1875.

•Kimmins J.P. 1997. **Forest ecology a foundation for sustainable management.** Upper Saddle River, New Jersey: Prentice Hall; 596 p.
Content: A textbook focused on ecosystems and how they change over time.
Applicable to: All ecosystem elements.
Critical Findings Refer to textbook.

•Kuchler, W. 1966. **Potential natural vegetation.** USDI Geological Survey 1969, Sheet No. 90.
Content: A potential natural vegetation classification system.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: Refer to paper and to Keeler-Wolf (1989).

•Lambert S.; Stohlgren, T.J. 1988. **Giant sequoia mortality in burned and unburned stands.** Journal of Forestry: 44-46.
Content: The extent to which recent prescribed fires may have caused mortality of giant sequoia trees in Giant Forest Grove is studied.
Applicable to: fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Low rates of giant sequoia mortality were observed in both the burned and unburned areas. Trees fire scarred in the center had higher mortality rates in unburned areas than in burned areas but the difference was not statistically significant. In unburned areas, the highest small stem mortality was observed in pure, dense patches of giant sequoia saplings.

•Lang, R. 1986. **Integrated Approaches to Resource Planning and Management.** University of Calgary Press, Calgary, Alberta, Canada.
Content: An overview of integrated resource management.
Applicable to: All aspect of ecosystem management.
Critical Findings: Refer to the report.

•Lawrence, G.; Biswell, H. 1972. **Effect of forest manipulation on deer habitat in giant sequoia**. Journal of Wildlife Management 36(2): 595-605.
Content: A report documenting the results of a study investigating the effects of removing understory trees and debris in a giant sequoia grove on summer forage available to mule deer.
Applicable to: Vegetation mosaic and animal species ecosystem elements.
Critical Findings: "On areas treated by cutting, piling, and burning, the browse and other forage was more abundant, more closely utilized, and more nutritious than on untreated control areas. The vegetational responses to the forest treatment reflected the increased sunlight and openness of the canopy."

•Leuschner, W.A. 1984. **Introduction to forest resource management**. New York: John Wiley and Sons, Inc.; 298 p.
Content: A forest management textbook.
Applicable to: All aspects of ecosystem management.
Critical Findings: Refer to the textbook for a description of various forest management approaches (e.g., even-age versus uneven-age).

•McKelvey, Kevin S.; Johnston, James D. 1992. **Historical perspectives on forests of the Sierra Nevada and the Transverse Ranges of southern California: forest conditions at the turn of the century**. In: Verner, J.; McKelvey, K.S.; Noon, B.R.; Gutierrez, R.J.; Gould Jr., G.I.; Beck T.W., technical coordinators. The California spotted owl: a technical assessment of its current status. Gen. Tech. Rep. PSW-GTR-133. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 225-246.
Content: Historical perspectives on vegetation development in the Sierra Nevada.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: The authors provide a description of stand, structure, and species composition changes that occurred since presettlement times. A pictorial record of those changes is provided.

•McKelvey, K.S.; Skinner, C.N.; Chang, C.; Erman, D.C.; Husari, S.; Parsons, D.J.; van Wagtendonk, J.W.; Weatherspoon, C.P. 1996. **An overview of fire in the Sierra Nevada**. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chap. 37. Davis, CA: University of California, Centers for Water and Wildland Resources.
Content: An overview of fire in the Sierra Nevadas.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Fire has been and will continue to be a major influence of Sierra Nevada landscapes. Human uses and management activities over the last 150 years have altered fire regimes. There are more areas today in the Sierra Nevada that would more readily support more uniform severe large fires than were characteristic of presettlement conditions.

•McKelvey, K.S. 1998. **Personal communication.**
Content: Discussion with Bob Rogers (November 6, 1998) on snags in mixed conifer-giant sequoia groves.
Applicable to: Organic debris ecosystem element and snag density indicator.
Critical Findings: Refer to text of this report.

•Manley, P.N.; Brogan, Gary E.; Cook, Carolyn; Flores, Mary E.; Fullmer, Donald G.; Husari, Susan; Jimenson, Thomas M.; Lux, Linda M.; McCain, Michael E.; Rose, Judy A.; Schmitt, Gary; Schuyler, John C.; Skinner, Michael. 1995. **Sustaining ecosystems-a conceptual framework**. San Francisco, CA: USDA Forest Service Pacific Southwest Region. Report No. R5-EM-TP-001.
Content: A conceptual framework and an analysis process for sustaining ecosystems in the Pacific Southwest Region of the Forest Service is provided in this report.
Applicable to: Ecosystem management
Critical Findings: This report is one of the first efforts to document an analysis process to implement ecosystem management in the Pacific Southwest Region of the Forest Service. Key terms, concepts and principles are discussed. A 14 step landscape-to-project ecosystem management process is provided.

•Miller P.R.; Grulke, N.E.; Stolte, K.W. 1994. **Air pollution effects on giant sequoia ecosystems**. In: Aune, P.S., technical coordinator. Proceedings of the symposium on giant sequoias: their place in the ecosystem and society; 1992 June 23-25; Visalia, CA. Gen. Tech. Rep. PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 90-98.
Content: Studies were undertaken to 1) test the visible injury and growth responses of seedling giant sequoias to ozone or ozone plus sulfur dioxide in open-top fumigation chambers; 2) evaluate the morphological responses and gas exchange responses of both seedlings and large saplings in fumigation trials. Possible stand-level consequences of chronic exposure of giant sequoia and companion tree species in native stands are discussed. The study was conducted in Sequoia and Kings Canyon National Parks.
Applicable to: Air quality ecosystem element.
Critical Findings: The authors conclude: "Thus, present ambient levels of ozone exposure in Sequoia and Kings Canyon National Parks are sufficient to cause detectable ozone injury to recently emerged seedling." They further state "If ozone air quality should deteriorate more, it is possible that ozone could act as a new selection pressure during early seedling stage." However, the authors also found that large saplings of giant sequoia did not reveal any impairment after exposure for 2 months to concentrations up to 3X ambient ozone.

•Muir, J. 1961. **The mountains of California**. Garden City, New York: Doubleday and Company; 300 p.
Content: John Muir's experiences and viewpoints regarding the Sierra Nevada some of which are specific to giant sequoia groves.
Applicable to: All aspects of ecosystem management.
Critical Findings: Refer to the book.

- Myers, T.J.; and Swanson, S. 1992. **Variation of stream stability with stream type and livestock bank damage in northern Nevada**. Water Resources Bulletin AWRA 28(4): 459-486.
  Content: Stream stability rating indicator variables related to stream types and levels of ungulate bank damage.
  Applicable to: Stream morphology, sediment, and water ecosystem elements.
  Critical Findings: Range managers should consider the stream type when setting local standards, written management objectives, or determining riparian grazing strategies. Stream type is important for estimating potential response to management of a stream reach. Stream stability indicators are discussed.
- Nechodom, Mark. 1998. [Letter to Douglas Piirto and Robert Rogers]. 1998 December 28. Located in author's files.
  Content: Nechodom provides review comments and suggestions.
  Applicable to: The social ecosystem element.
  Critical Findings: Nechodom concludes that this paper represents an important contribution to the practical and applied literature on integrated analyses of ecological and social systems. He concludes, "However, as a final caveat, integration of social and economic dimensions into ecosystem management in planning should not proceed under the assumption that the goal is to minimize or narrow the difficult terrain of political negotiation. Scientific information plays an utterly critical role in that process, but it should not be assumed that scientific information vitiates the need for negotiation of diverse values."
- Parmeter, J.R. 1985. **Diseases and insects of giant sequoia**. In: Weatherspoon, C.P.; Iwamoto, Y.R.; Piirto, D.D., technical coordinators. Proceedings of the workshop on management of giant sequoia; 1985 May 24-25; Reedley, CA. Gen. Tech. Rep. PSW-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 17-18.
  Content: Insects and diseases associated with the giant sequoia at various stages of development are described.
  Applicable to: Vegetation mosaic and organic debris ecosystem elements.
  Critical Findings: Pest impacts in young and old giant sequoia trees are described. Refer to the paper for details.
- Parsons, D.J. 1978. **Fire and fuel accumulation in a giant sequoia forest**. Journal of Forestry 76: 104-105.
  Content: A study on fuel accumulation and its relationship to fire conducted in the Redwood Mountain area of Sequoia and Kings Canyon National Parks.
  Applicable to: Fire and organic debris ecosystem elements.
  Critical Findings: The total fuel accumulation of all ground fuels, including both woody material and the litter and duff layer was 85 tons/acre in the unburned forest. Burning reduced this amount to 9.3 tons/acre. This value gradually increased to 45 tons/acre over the next 7 years.
- Parsons, D.J.; DeBenedetti, S.H. 1979. **Impact of fire suppression on a mixed-conifer forest**. Forest Ecology and Management 2: 21-33.

Content: A report on the impact of 100 years of fire suppression in 4 forest types within the mixed conifer forest zone in Sequoia and Kings Canyon National Parks.
Applicable to: Fire and organic debris ecosystem elements.
Critical Findings: A shift in successional patterns, increased density of small trees particularly the shade tolerant white fir, and unnatural accumulation of ground fuels has resulted from over 100 years of fire suppression in the mixed conifer forest. Ladder fuels capable of conducting fire into the crowns of mature trees have increased. Giant sequoia show poor reproduction in the absence of fire.

- Parsons D.J.; Nichols, H. Thomas. 1986. **Management of giant sequoia in the national parks of the Sierra Nevada, California**. In: Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, Douglas D., technical coordinators. Proceedings of the workshop on management of giant sequoia; 1985 May 24-25; Reedley, CA. Gen. Tech. Rep. PSW-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, U.S. Department of Agriculture; 26-29.
Content: The history and evolution of fire management policy in Sequoia, Kings Canyon, and Yosemite National Parks is discussed.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: The need for maintaining and, where necessary, restoring natural ecosystem processes is emphasized.
- Patterson III, W.A.; Prentice, I.C. 1985. **Quantitative interpretation of fossil pollen spectra: dissimilarity coefficients and the method of modern analogs**. Quarternary Research 23: 87-108.
Content: A paper on quantitative interpretation of fossil pollen spectra.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: As climates change, the many factors that influence composition and structure of forest communities also change.
- Pfankuch, D.J. 1975. **Stream reach inventory and channel stability evaluation**. USDA Forest Service, R1-75-002. Government Printing Office #696-260/200, Washington DC.; 26 p.
Content: A field procedure to provide the observer with a range of information about a specific point (i.e., reach) of a stream.
Applicable to: Stream morphology, sediment, and water ecosystem elements.
Critical Findings: A report on field procedures to systemize measurements and evaluations of the resistive capacity of mountain stream channels to the detachment of bed and bank materials and to provide information about the capacity of streams to adjust and recover from potential changes in flow and/or increases in sediment production.
- Piirto, D.D. 1977. **Factors associated with tree failure of giant sequoia**. Berkeley: University of California; 155 p. Ph.D. dissertation.
Content: A study focused on investigating causes of failure of old-growth giant sequoia trees.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Advanced decay and fire scars were the most frequently observed factors associated with failure of old-growth giant sequoia trees. In 21

of 33 study trees (64 percent), one-third or more of the roots in the failure zone were too decayed to provide support. Both decay and carpenter ants were frequently associated with fire scars. Twenty-seven of the 33 study trees possessed fire scars, and 26 fell toward the scarred side. Nine Basidiomycetes were associated with decayed wood. Refer to the report for a listing of these Basidiomycetes. Physical disturbances were found associated with 22 of the 33 study trees. Methods to detect decay in fallen giant sequoia trees were examined. Wood properties (i.e., anatomical characteristics, specific gravity, content and properties of extractives, and decay resistance) which might be related to tree failure were also studied.

• Piirto, D.D. 1991. **Giant sequoia groves, a relic to be preserved or a resource to be managed**. Witness statement presented at the 1991 September 4 hearing of the Congressional Committee on Interior and Insular Affairs held in Visalia, CA.
Content: A witness statement presented at the September 4, 1991 hearing of the committee on interior and insular affairs.
Applicable to: All aspects of ecosystem management of national forest giant sequoia groves.
Critical Findings: It is not in the best interest of national forest giant sequoia groves to isolate them as relics of the past. Flexible management strategies and continued research are recommended. Refer to the statement for additional information.

• Piirto, D.D. 1994. **Giant sequoia insect, disease, and ecosystem interactions**. In: Aune, P.S., technical coordinator. Proceedings of the symposium on giant sequoias: their place in the ecosystem and society; 1992 June 23-25; Visalia, CA. Gen. Tech. Rep. PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 82-89.
Content: Insect, disease, and ecosystem interactions.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: The ability of individual giant sequoia trees to survive over long periods of time has often been attributed to species high resistance to disease, insect, and fire damage. Such a statement, however, is a gross oversimplification, given broader ecosystem and temporal interactions. The following topics are addressed: insect relationship; disease relationships; factors associated with tree failure; fungal agents associated with decay; fire/pathogen interactions; wounds as entrance courts.

• Piirto, D.D.; Parmeter Jr., J.R.; Cobb, F.W. 1974. ***Fomes annosus* in giant sequoia**. Plant Disease Reporter 58(5): 478.
Content: A report of *Fomes annosus* in giant sequoia.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: *Fomes annosus* was found associated with 16 of 20 giant sequoia tree failures.

• Piirto, D.D.; Parmeter Jr., J.R.; Wilcox, W.W. 1977. ***Poria incrassata* in giant sequoia**. Plant Disease Reporter 61(1): 50.
Content: A report of *Poria incrassata* in giant sequoia.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.

Critical Findings: *Poria incrassata* was found associated with root and butt rot of two fallen, old-growth giant sequoia trees at the University of California Whitaker's Experimental Forest.

- Piirto, D.D. and Wilcox, W. Wayne. 1981. **Comparative properties of old-growth and young-growth giant sequoia of potential significance to wood utilization.** Division of Agricultural Sciences, University of California. Bulletin 1901: 26 p.
  Content: A paper on the wood properties of old- and young-growth giant sequoia.
  Applicable to: Organic debris and the vegetation mosaic ecosystem elements.
  Critical Findings: Refer to the paper.
- Piirto, D.D.; Wilcox, W. Wayne; Parmeter, John R.; Wood, David L. 1984a. **Causes of uprooting and breakage of specimen giant sequoia trees**. Division of Agricultural and Natural Resources, University of California. Bulletin 1909: 14 p.
  Content: A study of the causes of uprooting and stem failure in old-growth giant sequoia. This paper is based on the results presented in a Ph.D. dissertation (Piirto 1977).
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: Advanced decay and fire scars were the most frequently observed factors associated with fallen giant sequoia trees. In 21 of 33 study trees, one-third or more of the roots were judged too decayed to provide support. Refer to the paper and to Piirto (1977) for further information.
- Piirto, D.D.; Parmeter, J.R.; Wilcox, W.W. 1984b. **Basidiomycete fungi reported on living or dead giant sequoia or coast redwood**. University of California Berkeley Forestry and Forest Products No. 55.
  Content: A listing of Basidiomycete fungi reported on giant sequoia and coast redwood.
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: Seventeen references and herbarium records were searched to provide this listing of Basidiomycete fungi associated with giant sequoia and coast redwood.
- Piirto, D.D.; Hawksworth, J.; Hawksworth, M. 1986. **Giant sequoia sprouts**. Journal of Forestry 84(9): 24-25.
  Content: First known report to describe the occurrence of sprouting in giant sequoia.
  Applicable to: Vegetation mosaic ecosystem element.
  Critical Findings: Refer to the paper.
- Piirto, D.D.; Piper, K.; Parmeter Jr., J.R. 1992a. **Final Report. Biological and management implications of fire/pathogen interactions in the giant sequoia ecosystem; part I--fire scar/pathogen studies**. San Luis Obispo, CA: Natural Resources Management Department, California Polytechnic State University. 316 p.
  Content: A fire/pathogen interaction study in the giant sequoia ecosystem.
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: A quantitative evaluation of the extent of circumference and cross-sectional area affected by fire scars in giant sequoia showed as much as 70

percent of the circumference (values ranged from 3.3 percent to 69.5 percent) and as much as 54 percent of the cross-sectional area (values ranged from 3.2 percent to 53.7 percent) affected. Reburning (i.e., prescribed burning) affects the callus tissue healing process on fire scarred giant sequoia trees. Bird activity, carpenter ant activity, and decay were significantly affected by prescribed burning operations when compared to unburned areas. Microfungi were found associated with fire scars and decay activity.

- Piirto, D.D.; Cobb Jr., F.W.; Workinger, A.; Otrosina, W.J.; Parmeter Jr., J.R. 1992b. **Final Report. Biological and management implications of fire/pathogen interactions in the giant sequoia ecosystem; part II--pathogenicity and genetics of *Heterobasidion annosum*.** San Luis Obispo, CA: Natural Resources Management Department, California Polytechnic State University. 33 p.
  Content: The role of *Heterobasidion annosum (i.e., Fomes annosus)* in the giant sequoia ecosystem was examined.
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: Isolates of *H annosum* from true fir and giant sequoia belong to the 'S' intersterility group. Additional genetic analyses and greenhouse seedling inoculation trials to determine host specificity were performed. The isolates of *H annosum* are capable of causing pathogenesis in true fir and giant sequoia. These results provide additional evidence to support the hypothesis that increasing white fir density in giant sequoia ecosystems in the absence of natural or prescribed fire may result in a build-up of *H annosum* inoculum that could affect giant sequoia trees.
- Piirto, Douglas D.; Rogers, R.R.; Bethke, M.C. 1997. **Communicating the role of science in managing giant sequoia groves.** In: Murphy, Dennis; Loftus, Nelson, technical coordinators. Proceedings of the National Silviculture Workshop; 1997 May 19-22; Warren, PA. Gen. Tech. Rep. GTR-NE-238. Radnor, PA: Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 48-57.
  Content: History of human association with giant sequoia as it relates to ecosystem management is discussed. Three management goals for national forest giant sequoia groves are proposed.
  Applicable to: All aspects of ecosystem management of national forest giant sequoia groves with a focus on the attitudes, beliefs, and values element.
  Critical Findings: The lessons learned from human association with giant sequoia are listed and discussed in the context of their importance to current ecosystem management thinking. An attempt to define the goals of protect, preserve (i.e., conserve), and restore for national forest giant sequoia groves is included in the paper.
- Piirto, Douglas D.; Parmeter Jr., John R.; Cobb Jr., Fields W.; Piper, Kevin L.; Workinger, Amy C.; Otrosina, William J. 1998. **Biological and management implications of fire-pathogen interactions in the giant sequoia ecosystem.** In: Pruden, Teresa L.; Brennan, Leonard A., technical coordinators. Proceedings of the 20th Tall Timbers Fire Ecology Conference, Fire in Ecosystem Management: Shifting the Paradigm from Suppression to Prescription; 1996 May 7-10; Boise, ID. Tallahassee, FL: Tall Timbers Research Station; 325-336.

Content: A paper publishing the results of the Piirto et al. (1992a, b) studies.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Refer to the Piirto et al. (1992 a, b) studies and to this paper.

- Pillsbury, N.H.; DeLasaux, M.J.; Dulitz, D. 1991. **Young-growth Sierra redwood volume equations for Mountain Home Demonstration State Forest**. California Forestry Note No. 103.
  Content: Volume estimation equations for young-growth giant sequoia were developed for determining cubic foot and Scribner board foot volume
  Applicable to: Vegetation mosaic ecosystem element.
  Critical Findings: Three different equation types were developed: local, standard, and Girard's form class. The new equations provide a more accurate estimate of volume than previous published equations for young-growth giant sequoia.
- Pinchot, Gifford. 1947. **Breaking new ground**. Harcourt, Brace, and Company, Inc.; 522 p.
  Content: Autobiography of Gifford Pinchot, first Chief of the USDA Forest Service.
  Applicable to: All ecosystem elements.
  Critical Findings: This autobiography discusses the life of Gifford Pinchot with a focus on the story of how practical forestry came to America, and how American forestry, in turn, gave birth to the movement for conservation of natural resources.
- Rogers, Robert. 1997. **Deer Creek Grove protection strategy** An unpublished report available from USDA Forest Service, Sequoia National Forest, 900 West Grand Avenue, Porterville, CA.
  Content: This report documents the results of a public collaboration and left-side analysis effort in compliance with National Forest Management Act requirements to develop a fire protection strategy for the Deer Creek Grove area on Sequoia National Forest.
  Applicable to: All ecosystem elements identified as being important to national forest giant sequoia grove management.
  Critical Findings: Specific information on the process used and subsequent findings are documented in this report. A discussion of reference variability for selected ecosystem elements is included in the report."
- Rogers, Robert [Letter to Douglas Piirto]. 1998 April 22. Address inquiries to R. Rogers, c/o USDA Forest Service, Sequoia National Forest, Porterville, CA.
  Content: A current listing of all giant sequoia groves by ownership.
  Applicable to: Giant sequoia ecosystem management.
  Critical Findings: A current estimate of size by ownership category of all giant sequoia groves is shown in a spreadsheet table. This estimate is more current than those provided in Rundel (1972) and Willard (1995).
- Rosgen, D.L. 1985. **A stream classification system**. In Riparian ecosystems, their management; reconciling conflicting uses. First North American Riparian Conference; 1985 April 16-18; Tucson, AZ. Gen. Tech. Rep. RM-120. Forest Service, U.S. Department of Agriculture; 95-100.
  Content: A stream classification system is proposed.

Applicable to: Stream channel morphology, sediment, and water ecosystem elements.
Critical Findings: Refer to paper and to Rosgen (1996).

- Rosgen, D.L. 1994. **A classification of natural rivers**. In: CATENA, Interdisciplinary Journal of Soil Science, Hydrology, and Geomorphology. International Society of Soil Science 22(3): 169-199.
  Content: A system for river and stream classification is proposed.
  Applicable to: Stream channel morphology, sediment, and water ecosystem elements.
  Critical Findings: Refer to paper and to Rosgen (1996).
- Rosgen, D.L. 1996. **Applied river morphology**. Wildland Hydrology, 1481 Stevens Lake Road, Pagosa Springs, Colorado.
  Content: A textbook documenting Rosgen's 31 years of natural stream and river systems investigations.
  Applicable to: Hydrology hierarchy; stream channel morphology, sediment and water ecosystem elements; associated environmental indicators.
  Critical Findings: Fundamental principles of river systems, stream classification, geomorphic characterization, morphological description, assessment, field data verification, and applications are discussed. Rosgen channel types and assessment strategies are described.
- Rundel, P.W. 1969. **The distribution and ecology of the giant sequoia ecosystem in the Sierra Nevada, California**. Durham, NC: Duke University; 204 p. Ph.D. dissertation.
  Content: A Ph.D. dissertation.
  Applicable to: Fire and vegetation mosaic ecosystem elements.
  Critical Findings: Refer to the publications that were developed from this dissertation.
- Rundel, P.W. 1971. **Community structure and stability in the giant sequoia groves of the Sierra Nevada, California**. The American Midland Naturalist 85(2): 478-492.
  Content: A report describing the existing understory and overstory vegetation composition in several giant sequoia groves (e.g., Muir Grove, North and South Calaveras, Whitaker's Forest, Redwood Mountain Grove.
  Applicable to: Fire and vegetation mosaic ecosystem elements.
  Critical Findings: Rundel observed the following:
  - Giant sequoia groves are differentiated from adjacent mesic habitats only by the presence of giant sequoia.
  - Disturbance history affects species composition and structure with incense-cedar, for example, showing a marked increase in fire (e.g., North Calaveras Grove) and logging disturbed (e.g., Whitaker's Forest) areas, both of which are generally low elevation groves where you would expect to find more incense-cedar.
  - White fir has always been a dominant tree in terms of relative density in most if not all of the giant sequoia groves with relative density values ranging from 53.7 percent in North Calaveras Grove to 85.4 percent in Muir Grove.

The relative dominance of white fir ranges from 20.3 percent in Redwood Mountain Grove to 40.4 in Muir Grove.
• Giant sequoia have a relative density that ranges from 5.0 percent in north Calaveras Grove to 11.4 percent in Muir Grove. Giant sequoia trees occupy the greatest proportion of the total basal area per acre (i.e., relative dominance) ranging from 57.3 percent in Muir Grove to 73.1 percent in Redwood Mountain (Hartesveldt et al. 1967).
• The relative density of incense-cedar ranges from 0.3 percent in Muir Grove to 36.6 percent in North Calaveras Grove. The relative dominance of incense-cedar ranges from less than 1 percent in Redwood Mountain to 10.9 percent in North Calaveras Grove.
• The relative frequency of sugar pine ranges from 3.3 percent in Muir Grove to 7.1 percent in south Calaveras Grove. The relative dominance of sugar pine ranges from 2.3 percent in Muir Grove to 9.9 percent in South Calaveras Grove.
• Ponderosa pine has a relative frequency and relative dominance of less than 1 percent and occurs with California Black Oak on drier sites within giant sequoia grove.
• Red fir is known to be an important associate in giant sequoia groves above 6,500 feet (e.g., Redwood Mountain Grove, Atwell Grove, Garfield Grove, Freeman Creek Grove, and Long Meadow Grove (Rundel 1971).
• Less common associates include Jeffrey pine, Douglas-fir, Pacific yew, Pacific Dogwood, California hazel, white alder, Scouler willow, bigleaf maple, bitter cherry, and canyon live oak. Douglas-fir, for example, is known to occur in minor amounts in the northern most groves (e.g., Placer Grove).
• Whereas the groundcover vegetation in many giant sequoia groves is considered sparse, the number of species present in the ground cover flora is considerable. Rundel lists 56 ground cover species occurring in Muir Grove, 33 species in North Calaveras Grove, and 82 species in South Calaveras Grove. He compares this number of groundcover vegetation species to other reports in the literature (e.g., Kilgore 1968, Hartesveldt and Harvey 196-).

•Rundel, P.W. 1972a. **An annotated list of the groves of Sequoiadendron giganteum in the Sierra Nevada--Pt. I.** Madrono 21(5): 319-328.
Content: A listing of giant sequoia groves.
Applicable to: All ecosystem elements.
Critical Findings: The name, location and remarks are provided in a listing of 75 giant sequoia groves known at that time to occur in California.

•Rundel, P.W. 1972b. **Habitat restriction in giant sequoia: the environmental control of grove boundaries**. The American Midland Naturalist 87(1): 81-99.
Content: A study of the relationship of Giant Forest Grove boundaries to water availability.
Applicable to: Ecosystem elements, environmental indicators, reference variability.
Critical Findings: "The maintenance of grove boundaries is controlled by an interaction of moisture availability, temperature and the tolerances of the seedling stage of giant sequoia."

• Rundel, P.W. 1973. **The relationship between basal fire scars and crown damage in giant sequoia**. Ecology 54(1): 210-213.
Content: A report documenting the results of a study on the relationship between basal fire scars and crown damage in giant sequoia.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: A strong correlation exists between the presence of basal fire scars in giant sequoia and the occurrence of snag tops in mature trees. It was reported that 50 percent of the giant sequoia trees with a fire scar greater than 100 square feet possess a sang top. This fire damage to the base of mature giant sequoia trees causes a significant reduction in the active xylem tissue available for water absorption. Less water is transported up a fire scarred damaged tree which in turn is thought to be connected to the higher prevalence of snag tops. Low water potentials (i.e., perhaps lower than -20 bars) may be an important limiting factor in determining the upper height limit of basal fire damaged giant sequoia trees.

• Schramm, G. 1980. **Integrated river basin planning in a holistic universe**. Nat. Res. J. 20: 787-806.
Content: River basin planning.
Applicable to: The water ecosystem element.
Critical Findings: Refer to paper.

• Shulman, D.; Gelobter, A. 1996. **Evaluating potential loss from wildfire of specified forest and stand attributes on Sequoia National Forest**. Unpublished draft report (dated 2/96) on file in the Porterville office of Sequoia National Forest.
Content: A wildfire severity model developed for Sequoia National Forest.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: The purpose of the wildfire severity model was to evaluate potential loss of spotted owl habitat in event of wildfire during 90th percentile weather burning conditions. All giant sequoia groves on Sequoia National Forest, and associated influence zones, were also evaluated using the outputs of this model (refer to Rogers 1997). This report documents a pioneering effort to characterize the risk of high severity fire in Sequoia National Forest giant sequoia groves.

• Shellhammer, H.S.; Stecker, R.E.; Harvey, H.T.; Hartesveldt, R.J. 1970. **Unusual factors contributing to the destruction of young giant sequoias**. Madrono 20(8): 408-410.
Content: A report of dead and dying young giant sequoia trees (1-11 years old) in the Cherry Gap Grove, Sequoia National Forest.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: Meadow mice and/or pocket gophers were associated with mortality of 54 out of 150 dead giant sequoia saplings. *Hypholoma fasciculare* and cerambycid beetles were also found associated with the dead saplings.

• Skaggs, Brent. 1996. **Analysis of the Starvation giant sequoia grove complex**. An unpublished report available from USDA Forest Service, Sequoia National Forest, 900 West Grand Avenue, Porterville, CA.

Content: An unpublished report prepared in part to complete requirements for the Technical Fire Management course offered through Washington Institute.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: This report contains excellent site-specific fuel loading and forest structure data for Starvation Grove on Sequoia National Forest. Data collected by Oscar Evans in 1929 for Starvation Grove was compared to inventory data collected in 1995. Starvation Grove has missed four fire return cycles since 1857 resulting in a marked increase of white fir and incense-cedar and a drop in ponderosa pine and sugar pine.

•Skinner, C.N.; Chang, C. 1996. **Fire regimes, past and present**. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chap. 38. Davis, CA: University of California, Centers for Water and Wildland Resources.
Content: A current review of the role of fire in the Sierra Nevada. Fire history and fire effects for the major vegetation types/ecosystems that occur in the Sierra Nevada are discussed.
Applicable to: Fire ecosystem element; indicators of fire severity, fire return interval, weight of down material indicator, snag density, plant community indicator, patch and gap size.
Critical Findings: The past (i.e., prior to Euroamerican settlement around 1850) and present fire regimes were evaluated for a variety of Sierra Nevada ecosystems. Fire frequency and severity varied spatially and temporally depending upon elevation, topography, vegetation, edaphic conditions, and human cultural practices. The authors conclude that: "Euroamerican settlement and associated management activities in Sierran ecosystems over the last 150 years or so have caused many changes in Sierran fire regimes and in the vegetation associated with those regimes...Developing forest structures and landscape patterns that are comparable to those that developed under the more frequent fire regimes of the past will plausibly help ameliorate the ecosystem disruptions caused by the severe fires that are beyond fire-suppression capabilities."

•Slocombe, D.S. 1993a. **Environmental planning, ecosystem science, and ecosystem approaches for integrating environment and development**. Environmental Management 17: 289-303.
Content: The main components of the ecosystem management approach are described.
Applicable to: All aspects of ecosystem management.
Critical Findings: Refer to the paper.

•Slocombe, D.S. 1993b. **Implementing ecosystem-based management**. BioScience 43(9): 612-622.
Content: A paper describing the development of theory, practice, and research for planning and managing a region.
Applicable to: All aspects of ecosystem management.
Critical Findings: Refer to the paper.

•Smith, D.M.; Larson, B.C.; Kelty, M.J.; Ashton, P.M.S. 1997. **The practice of silviculture, applied forest ecology**. 9th ed. New York: John Wiley & Sons, Inc.; 537 p.

Content: A contemporary textbook about silviculture, applied forest ecology, and their connection to ecosystem management.
Applicable to: Vegetation mosaic reference variability.
Critical Findings: A collection of ideas about silviculture and analytical approaches to its practice.

- Stark, N. 1968. **The environmental tolerance of the seedling stage of *Sequoiadendron giganteum*.** The American Midland Naturalist 80(1): 84-95.
Content: This study describes the range of ecological tolerance of giant sequoia seedlings to soil moisture, light intensity, and soil pH. Giant sequoia seedlings were grown in an experimental plot at the Stanislaus Experiment Station, Old Strawberry and were subjected to a variety of environmental conditions.
Applicable to: Atmospheric and vegetation mosaic ecosystem elements.
Critical Findings: The author reports several major findings: infection of giant sequoia seedlings by high temperature root rot such as *Sclerotium bataticola* slows growth initiation, and limits growth and survival; giant sequoia seedlings can survive in shaded areas but grow poorly; giant sequoia seedlings grow best in full sunlight; seedlings grow best in soils with a pH of 6; seedling height and survival decreases as soil moisture in the root zone drops from 16 percent to 5 percent; giant sequoia seedlings can develop a two-storied root system which is well suited to summer drought. The author concludes: "The young trees [giant sequoia seedlings] are more drought resistant than previously thought, and capable of growing and surviving under a wide range of soil moisture and shading conditions."
- Starrs, P.F. 1996. **The public as agents of policy**. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chap. 6. Davis, CA: University of California, Centers for Water and Wildland Resources.
Content: An overview of policy evolution in the Sierra.
Applicable to: Attitudes, beliefs, and values ecosystem element, expression of realized expectations indicator, recognition and incorporation of diverse values and beliefs indicator.
Critical Findings: The author concludes "...the Sierra's landscapes have gone through a series of important evolutions driven by two forces, one essentially vernacular and improvisational, and the other perpetually reactive and establishment oriented." Five broad themes are introduced in this paper to support this conclusion.
- Stephens, S.L. 1995. **Effects of prescribed and simulated fire and forest history of giant sequoia (*Sequoiadendron giganteum* [Lindley] Buchholz)-mixed conifer ecosystems of the Sierra Nevada, California.** Berkeley: University of California; 108 p. Ph.D. dissertation.
Content: Reported in this dissertation are the results of several studies focused on evaluating the effects of prescribed and simulated fire.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: The author reports on the following studies:
  - The effects of fire on giant sequoia-mixed conifer tree species: a model of tree mortality.

• The effects of opening size and slash treatment on giant sequoia regeneration in a group selection silvicultural system.
• The effects of fuel treatments on potential fire behavior and effects in a giant sequoia-mixed conifer ecosystem in the Sierra Nevada.
• Forest history and analysis of giant sequoia-mixed conifer inventory data of the southern Sierra Nevada from 1900-1901.
• Fuel load and bulk density of ponderosa pine and white fir forest floors.
• One of the most immediate consequences of increased fuels is an increased hazard of wildfires sweeping through groves with a severity rarely encountered in pre-European times.

• Stephens, S.L. 1998. **Evaluation of the effects of silvicultural and fuels treatments on potential fire behavior in Sierra Nevada mixed-conifer forest.** Forest Ecology and Management 105(1998): 21-35.
Content: This paper models fire behavior in a mixed conifer forest and investigates how silvicultural and fuel treatments affect potential fire behavior. The FARSITE computer model was used to spatially and temporally model fire growth and behavior.
Applicable to: fire, organic debris and vegetation mosaic ecosystem elements.
Critical Findings: The prescribed burn, thinning, and biomassing followed by prescribed fire and salvage or group selection with slash and landscape fuel treatments resulted in the lowest average fireline intensities, heat per unit area, rate of spread, area burned, and scorch heights. These simulations show that salvage and group selection treatments must include a landscape fuel treatment to be effective in reducing the potential for large, high-intensity wildfires. Combinations of prescribed fire and/or mechanical treatments can be used to reduce fuel loads and fuel continuity in mixed-conifer ecosystems thus reducing the threat of large, intense wildfires.

• Stephens, Scott L.; Elliott-Fisk, Deborah L. 1998. **Sequoiadendron giganteum - mixed conifer forest structure in 1900-1901 from the southern Sierra Nevada, CA.** Madrono, Vol. 3.
Content: Historical data collected from eight mixed conifer and four giant sequoia-mixed conifer plots in the southern Sierra Nevada by George Sudworth in 1900-1901 were analyzed to determine historic forest structure.
Applicable to: Organic debris, fire, and vegetation mosaic ecosystem elements.
Critical Findings: Analysis of Sudworth's historic plot data within giant sequoia-mixed conifer areas suggests that the most common size classes were medium to large. This is in contrast to published studies of current stands that have determined small size classes of shade tolerant species are occurring at higher frequencies.

• Stephens, S.L.; Dulitz, D.J.; Martin, R.E. 1999. **Giant sequoia regeneration in group selection openings in the southern Sierra Nevada.** Forest Ecology and Management (in press).
Content: A report documenting the results of a study investigating the influence of opening size and three fuel treatments (tractor pile and burn, broadcast burn, lop and scatter) on giant sequoia germination, growth and survival.

Applicable to: Vegetation mosaic and fire ecosystem elements.
Critical Findings: No significant differences were detected in seedling density between the treatments. It was apparent, however, that the lop and scatter only treated units inhibited any regeneration of giant sequoia.

- Stephenson, N.L. 1987. **Use of tree aggregations in forest ecology and management**. Environmental Management 11(1): 1-5.
  Content: A review of two studies on the use of tree aggregation to analyze forest age-structure stability and past forest structure.
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: This paper is a critical review of the papers by Bonnicksen and Stone (1982a, b).
- Stephenson, N.L. 1994. **Long-term dynamics of giant sequoia populations: implications for managing a pioneer species**. Gen. Tech. Rep. PSW-151. Forest Service, U.S. Department of Agriculture.
  Content: Dynamics and management of giant sequoia groves.
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: The following conclusions were reported.
  - "Judging whether a grove is successfully reproducing cannot be based on the sizes of sequoias. Very small trees can be quite old, and the relationship between size and age is poor.
  - Sequoia populations were almost certainly near equilibrium or increasing before the arrival of European settlers.
  - In this century, there has been a massive failure of sequoia reproduction in groves protected from fire but otherwise meant to be maintained in a natural state.
  - Before the arrival of the European settlers, successful recruitment of mature sequoias depended on fires intense enough to kill the forest canopy in small areas.
  - Even-age patches of sequoias ranged from 0.03 ha (0.08 acres) to more than 0.4 ha (1 acre)."
- Stephenson, N.L. 1996. **Ecology and management of giant sequoia groves**. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chap. 55. Davis: University of California, Centers for Water and Wildland Resources.
  Content: A thorough review of the state-of-knowledge associated with management of giant sequoia groves.
  Applicable to: All the identified ecosystem elements, indicators and associated reference variability information identified as being important to national forest giant sequoia grove management.
  Critical Findings: Four broad conclusions were presented: 1) inaction threatens the sustainability of giant sequoia ecosystems; 2) managers must practice adaptive management; 3) land management agencies must cooperate; 4) permanent new base funding is needed. Stephenson reports:
  - a categorization and description of four giant sequoia grove management groups;
  - a brief review of several articles which address variability in fuel loading;
  - fuel loading ranging from 19 tons per acre to 134 tons per acre.

• a characterization of the fuel conditions for the four giant sequoia grove management classes.
• fuel conditions today are such that these formerly relatively rare, high-severity fires could become more common."

• Stephenson, N.L. [Letter to Douglas Piirto and Robert Rogers]. 1998 April 16. Located in author's files.
Content: Anecdotal observations on gap size frequency in the mixed conifer-giant sequoia forest.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements;
Critical Findings: Stephenson estimates that most presettlement gaps seem to be between 0.1 to 3.0 acres in size with modal gap size at 0.2 to 0.3 acres. Empirical data to support this approximation are needed.

• Stephenson, N.L.; Parsons, D.J.; Swetnam, T.W. 1991. **Restoring natural fire to the sequoia-mixed conifer forest: should intense fire play a role**. In: Proceedings of the 17th Tall Timbers Fire Ecology Conference, High Intensity fire in Wildlands: Management Challenges and Options; Tallahasse, FL, Tall Timbers Research Station, 321-337.
Content: A reassessment of natural fire regimes and fire intensity in the giant sequoia-mixed conifer forest.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements;
Critical Findings: In Sequoia National Park, some clumps of large sequoias such as the Parker , Senate , House , and Founders groups range in size from 0.1 hectares (0.25 acres) to 0.2 hectares (0.5 acres) with 5 to 20 large giant sequoia trees of similar size and presumably of similar age. The largest cohort of recent giant sequoia regeneration due to prescribed fire in Sequoia and Kings Canyon National Park is 4 hectares (10 acres) with patchiness of sequoia regeneration a function of patchiness of fire disturbance. The authors state: "...these observations of forest structure suggest that at least some natural fires burned hot enough to create local canopy gaps that subsequently set the stage for the abundant and successful recruitment of groups of new sequoias." They further state that "...natural fires may be best characterized as having been patches of high intensity fire within a matrix of low intensity fire, with the frequency and relative area covered by intense fires varying over time."

• Stephenson N.L.; Demetry, A. 1995. **Estimating ages of giant sequoias**. Can. J. For. Res. 25: 223-233.
Content: A method was developed to estimate tree age by combining knowledge of tree size with information gained from partial increment cores.
Applicable to: Vegetation mosaic ecosystem element.
Critical Findings: Equations were developed to estimate age. For giant sequoia stumps up to 3200 years old and 6.5 m in diameter, age estimates were within 10 percent of actual age 62 percent of the time, and within 25 percent of actual age 98 percent of the time, even when increment cores had sampled less than 20 percent of the bole radius, a substantial improvement over previously published methods which estimate tree age from diameter alone.

- Stohlgren, Thomas J. 1991. **Size distributions and spatial patterns of giant sequoia in Sequoia and Kings Canyon National Parks**. Davis: University of California; 300 p. Ph.D. dissertation.

  Content: A study of size distributions and spatial patterns of giant sequoia in 35 national park giant sequoia groves.

  Applicable to: Vegetation mosaic, fire, and organic debris ecosystem elements.

  Critical Findings: An important study which documents a range of conditions in 35 national park giant sequoia groves. Some of the important results are:

  - Most groves had complex size distribution that were bi-modal or multimodal suggesting complex population dynamics over time.
  - The exponential regression model provided a better fit to the size distribution for 24 of 31 national park groves with greater than 30 giant sequoia trees than did linear, logarithmic, or power models. Refer to Stohlgren's Figure 2-2.
  - Grove size with Sequoia and Kings Canyon National Parks (SEKI) varied from 1 acre (0.5 hectares) in Granite Creek to 1908 acres (772 hectares) in the Redwood Mountain Grove.
  - Mean tree diameter for the entire population of giant sequoias (i.e., 160,911 giant sequoia trees in 35 groves in SEKI is 24 inches +/- 0.12 inches (0.61 meters +/- 0.003 m). Stohlgren (1991) states that mean diameter varied considerably between groves ranging from 15 inches (0.39 meters) in Pine Ridge Grove to 92.1 inches (2.34 meters) in Devils Canyon Grove.
  - Groves containing more giant sequoia trees tended to have smaller mean tree diameters than groves with fewer trees (refer to Stohlgren's Table 2-2.
  - Total density of giant sequoia trees averaged for 31 groves is 14.5 +/- 1.9 trees per acre (35.8 +/- 4.7 trees per hectare). The range of values varied from 5.14 giant sequoia trees per acre (12.7 trees per hectare) in Sequoia Creek Grove which is 7 acres (3 hectares) in size to 48.77 giant sequoia trees per acre (120.5 trees per hectare) in Cedar Flat Grove which is 10 acres (4 hectares) in size. Giant Forest has 9.92 giant sequoia trees per acre (24.5 trees per hectare) as a comparison.
  - The total number of giant sequoia trees per grove varied from 1 in Putnam-Francis Grove to 66,751 in Redwood Mountain Grove.
  - Mean basal area per acre (240 square feet per acre +/- 15 square feet or 55.2 +/- 3.5 square meters per hectare) of giant sequoias for 30 groves with 30 or more giant sequoia trees varied little among groves despite large differences in grove size. The range of basal area per acre of giant sequoia trees varied from 89 square feet per acre (20.5 square meters per hectare) in Surprise Grove which is only 5 acres (2 hectares) in size to 463 square feet per acre (106.4 square meters per hectare) in Devils Canyon which also is only 5 acres (2 hectares) in size. Giant Forest by way of comparison, which is approximately 1880 acres (761 hectares), has a basal area density of 268 square feet per acre (61.6 square meters per hectare). These average values do not include the substantial amount of whitewood (e.g., white fir, sugar pine etc.) that also occur in giant sequoia groves.

• Graphic presentations are shown depicting the number of giant sequoia trees by diameter class for each of the 35 groves studied in SEKI. interpreted three general patterns of size class distribution:

a. an over-abundance of small giant sequoia trees followed by an under-abundance of many larger size class giant sequoia trees suggesting self-replicating populations in terms of size (e.g., Atwell, Castle Creek, East Fork, Garfield, Giant Forest, Pine Ridge, Redwood Meadow, Redwood Mountain, and South Fork Grove).

b. an under representation of the smallest trees and an over-representation of the moderate to large size class giant sequoia trees suggesting a lack of continuous recruitment of giant sequoia trees in terms of size (e.g., Eden, Homer's Nose, Board Camp, and Cedar Flat groves).

c. a more complex pattern where size distribution or departure profile that is bi- or multi-modal. Peaks and depression in frequency are highly variable in placement, magnitude, and intensity (e.g., Muir, Devils Canyon, Oriole Lake, Skagway, Dennison, Granite Creek, Horse Creek, New Oriole Creek, Sequoia Creek, and Suwanee groves). A complex pattern of recruitment not easily explained seems to have occurred in groves with this type of pattern. Stohlgren suggests that some combination of local disturbance history, competition, pathogens, microsite, microclimate, and possibly regional climate trends may be involved.

• 54.9 percent of the live tree giant sequoia basal area rests on a little over 5 percent of the populations (i.e., trees greater than 126 inches dbh (3.2 meters). Trees from 12 inches to 126 inches (0.3 to 3.2 meters) account for another 45 percent of the basal area. And, even though small giant sequoia trees represent 67 percent of the population of giant sequoia trees, they only represent less than 0.1 percent of the live basal area.

• Stohlgren also analyzed 1968 tree inventory data for Big Stump, a grove that was heavily logged between 1883 and 1889. Refer to Stohlgren (1992).

• Stohlgren, Thomas J. 1992. **Resilience of a heavily logged grove of giant sequoia (*Sequoiadendron giganteum*) in Kings Canyon National Park, California.** Forest Ecology and Management 54: 115-140.

Content: The vegetational response following logging in the Big Stump Grove. The grove was logged between 1883 and 1889.

Applicable to: Vegetation mosaic, fire, and organic debris ecosystem elements.

Critical Findings: The following results were reported:

• The estimated pre-logging basal area (247 square feet per acre or 56.7 square meters per hectare) was similar to the mean of 30 other giant sequoia groves.

• The 1968 measured basal area per acre post logging value, some 76-85 years later, was 110.0 square feet (25.25 square meters per hectare).

• The number of trees present in 1968 were as follows: trees less than 0.15 meter class (5.9 inches) averaged 11.9 trees per hectare (4.82 trees per acre); trees 0.15 to 3.2 meters (5.9 inches to 126 inches) averaged 53.1 trees per hectare (21.5 trees per acre); trees greater than 3.2 meters (126 inches) averaged 0.2 trees per hectare (0.1 trees per acre). The total number of trees per hectare in 1968 was 65.2 trees (26.4 trees per acre).

- Stohlgren states: "High tree density and fast growth rates (radial growth rate of trees less than 1.95 meters or less than 76.8 inches dbh averaged 6.1-6.8 mm per year or 0.24-0.27 inches per year) resulted in the recovery of approximately 45 percent of the basal area of giant sequoia after only 85 years." (Note Stephenson [1996] estimates 33 percent).
- It was also determined from these studies of the previously logged Big Stump Grove that patches of regeneration which are presently dominated by giant sequoias do not necessarily grow in the same places within the grove that were dominated by sequoias in pre-Euroamerican times.
- Stephenson (1996) further explains Stohlgren's (1991, 1992) work as follows: "Location of slash burning and other factors may have influenced this spatial redistribution of sequoia dominance. Because some sequoia seedlings became established beyond the original grove boundary, there was a small increase in grove area following logging."

- Stohlgren, Thomas. J. 1993a. **Spatial patterns of giant sequoia *(Sequoiadendron giganteum)* in two sequoia groves in Sequoia National Park, California**. Can. J. For. Res. 23: 120-132.

  <u>Content</u>: A study of size distributions and spatial patterns of giant sequoia in Sequoia and Kings Canyon National Parks. A publication that stemmed from his Ph.D. dissertation (Stohlgren 1991).

  <u>Applicable to</u>: Vegetation mosaic, fire, and organic debris ecosystem elements.

  <u>Critical Findings</u>: Various spatial analysis techniques showed that Muir Grove and Castle Creek Grove had dissimilar spatial patterns for similar sized tree even though they were similar in terms of area, elevation and number of giant sequoia trees present.

- Stohlgren, Thomas J. 1993b. **Intraspecific competition (crowding) of giant sequoias *(Sequoiadendron giganteum)***. Forest Ecology and Management 59: 127-148.

  <u>Content</u>: A study of intraspecific competition of giant sequoia in Sequoia and Kings Canyon National Parks. A publication that stemmed from his Ph.D. dissertation (Stohlgren 1991).

  <u>Applicable to</u>: Vegetation mosaic, fire, and organic debris ecosystem elements.

  <u>Critical Findings</u>: "Dead giant sequoia trees had a significantly higher crowding index than 561 live trees of similar diameter. It was interpreted from the data that dead giant sequoia trees of less than 16.6 cm dbh had a significantly greater mean number of live neighbors and mean crowding index than live sequoias of similar size. Intra-specific crowding may be an important mechanism in determining the spatial distribution of giant sequoias in old-growth forests."

- Swetnam, T.W. 1993. **Fire history and climate change in giant sequoia groves**. Science 262: 885-889.

  <u>Content</u>: Giant sequoia fire scars were used to reconstruct the spatial and temporal pattern of surface fires that burned episodically through five groves located along a north-south 93 mile (160 km) transect during the past 2000 years.

  <u>Applicable to</u>: Fire, organic debris, and vegetation mosaic ecosystem elements.

  <u>Critical Findings</u>: Swetnam found a mean fire return interval prior to 1860 of approximately 3 to 8 years with a maximum interval generally less than 15

years. Swetnam further found that the longest fire-free period in any grove was 30 years.

•Swetnam, T.W.; Touchan, R.; Baisan, C.H.; Caprio, A.C.; Browns, P.M. 1991. **Giant sequoia fire history in Mariposa Grove, Yosemite National Park**. In: Proceedings of the Yosemite centennial symposium; NPS D-374. Denver, CO: National Park Service; 249-255.
Content: A fire history study.
Applicable to: The organic debris, fire, and vegetation mosaic ecosystem elements.
Critical Findings: Refer to the paper.

•Swetnam, T.W.; Baisan, C.H.; Caprio, A.C.; Touchan, R.; Brown, P.M. 1992. **Tree-ring reconstruction of giant sequoia fire regimes**. Unpublished final report to Sequoia, Kings Canyon and Yosemite National Parks. Cooperative Agreement No. DOI 8018-1-0002. Tucson: University of Arizona, Laboratory of Tree Ring Research.
Content: A report documenting a major fire history conducted in the Sierra Nevadas.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: The authors state: "...Maximum fire frequencies within the sampled areas were as high as 3 to 4 fires per decade during the medieval warming period of A.D. 1000 to 1300. Lower fire frequency periods (1 to 2 per decade) occurred before A.D. 800. There were occasional fire-free intervals that lasted 20 to 30 decades. Large, high intensity fires were a rare event. One such fire occurred in A.D. 1297 in the Mountain Home Grove. Higher frequency periods were dominated by smaller fires and lower frequency periods had more widespread fires."

•Thomas, Jack Ward. 1993. **Forest management approaches on the public lands**. Albright Lecturer speech. University of California, Berkeley.
Content: Dr. Thomas, Chief of the Forest Service, made an invited speech as part of the Albright Lecturer program at the University of California, Berkeley.
Applicable to: Ecosystem management
Critical Findings: Chief Thomas publicly states the direction he provided to the Forest Service to implement ecosystem management in June 1992. Chief Thomas states "It is time to consider land use in a broader context than a series of single-use allocations to address specific problems or pacify the most vocal constituencies...We must...move to an expanded concept more in keeping with current scientific thinking..."

•Tilles, D.A.; Wood, D.L. 1982. **The influence of carpenter ant *(Camponotus modoc)* (Hymenoptera: Formicidae) attendance on the development and survival of aphids *(Cinara spp.)* (Homoptera: Aphididae) in a giant sequoia forest**. The Canadian Entomologist 114(12): 1133-1141.
Content: A study of ecosystem interactions between carpenter ants and aphids.
Applicable to: Fire and vegetation ecosystem element.
Critical Findings: Survival of abundant aphid colonies in the crowns of white fir trees is dependent to some extent on attendance by carpenter ants.

•Tweed, William. 1994. **Public perception of giant sequoia over time**. In: Aune, P.S., technical coordinator. Proceedings of the symposium on giant sequoias: their place in the ecosystem and society; 1992 June 23-25; Visalia, CA. Gen. Tech. Rep. PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 5-7.
Content: A paper addressing public perceptions of giant sequoia.
Applicable to: Attitudes, beliefs, and values ecosystem element.
Critical Findings: "Public perceptions regarding giant sequoia differ dramatically from those of land managers. Members of the public tend to perceive sequoias as unchanging, sacred objects, not as dynamic members of evolving ecosystems. These perceptions strongly color public expectations about how giant sequoia should be managed."

•University of California, Centers for Water and Wildland Resources. 1996a. **Sierra Nevada ecosystem project, final report to Congress, executive summary of the Sierra Nevada ecosystem project report**. Davis: University of California, Centers for Water and Wildland Resources;
22 p.
Content: An Executive Summary of the Sierra Nevada Ecosystem Project (SNEP).
Applicable to: All identified ecosystem elements important to the management of giant sequoia groves and surrounding areas.
Critical Findings: A brief description of the scope and background of the SNEP project, the 69 critical findings derived from assessments, overviews of the assessments, and a discussion of integrating information from assessments with possible solutions to Sierra Nevada problems.

•University of California, Centers for Water and Wildland Resources. 1996b. **Sierra Nevada ecosystem project, final report to Congress, vol. I, assessment summaries and management strategies**. Davis, CA: University of California, Centers for Water and Wildland Resources;
209 p.
Content: This volume contains the critical findings, the context of the study, summaries of the major points from the assessments and case studies in the other volumes, and a presentation of alternative strategies and their implications for the future health and sustainability of the ecosystem.
Applicable to: All identified ecosystem elements important to the management of giant sequoia groves and surrounding areas.
Critical Findings: There is a large amount of relevant information in this report. Some information that is particularly important to management of giant sequoia includes:

• A very good discussion of alternative views of the role of fire in the Sierra Nevada as it appears on page 63 is quoted below.

• "All SNEP scientists agree that fire has played a significant if not a dominant role in shaping the vegetation pattern; the departure of views begins with the relative certainty of fire frequency and spatial intensity in presettlement times. There is too little compelling evidence and incomplete rangewide research to conclude a precise pattern of fire frequency or severity in presettlement times.

There were very probably areas that burned frequently (less than 10-year intervals), but some areas within the same vegetation type probably escaped burning for much longer periods and built up sufficient fuel loads to burn with high intensity if ignition occurred during favorable burning conditions. This point of difference in views centers on the belief that there were probably many variations in the return frequencies and fire intensity pattern that contributed to the mosaic of vegetation patterns on the landscape today.

• A second major point of difference relates to the relative "openness" of forests before the disturbances caused by settlers. The alternative view concludes, from the same evidence, that forest conditions were not largely, "open or parklike" in the words of John Muir; rather, there was a mix of dark dense, or thick in unknown comparative quantities. Select early accounts support an open, parklike forest, but there were many similar accounts that describe forest conditions as dark or dense or thick. J. Goldsborough Bruff, a forty-niner who traveled the western slopes of the Feather River drainage between 1849 and 1851, kept a detailed diary. He clearly distinguished between open and dense forest conditions and recorded the dense condition six times more than the open. Many other accounts of early explorers (e.g., John C. Fremont, Peter Decker, William Brewer) identify dark or impenetrable forest; the presettlement forest was far from a continuum of open, parklike stands. From these records it seems clear that Sierran forests were a mix of different degrees of openness and an unknown proportion in dark, dense, nearly impenetrable vegetative cover from north to south and foothill to crest.

• A third point of departure has to do with the frequency of stand-terminating fires in presettlement times. One group concludes that such events were rare or uncommon. The alternative view is that stand-threatening fires were probably more frequent. They were heavily dependent upon combinations of prolonged drought, an accumulation of dead material resulting from natural causes (e.g., insect mortality, windthrow, snow breakage), and severe fire weather conditions of low humidity and dry east winds coupled with multiple ignitions, possibly from lightning associated with rainless thunderstorms. Such fires were noted during the last half of the nineteenth century by newspaper accounts, official reports, (John Leiberg, USGS, 1902), and diaries; most were apparently caused by settlers, stockmen, or miners. Fuel loads were obviously sufficient at that time, thus strongly suggesting that similar conditions existed in earlier times with unknown frequencies."

• A case study review of the Mediated Settlement for Sequoia National Forest(pages 154-159) developed by Doug Leisz.

•University of California, Centers for Water and Wildland Resources. 1996c. **Sierra Nevada Ecosystem Project, final report to Congress, vol. II, assessments and scientific basis for management options**. Davis, CA: University of California, Centers for Water and Wildland Resources.

Content: This volume contains the technical assessments of historical, physical, biological, ecological, social, and institutional conditions of the Sierra Nevada, selected case studies, details on the scientific basis and methods used in strategies, and references to the literature and data sources.

Applicable to: All identified ecosystem elements important to the management of giant sequoia groves and surrounding areas.
Critical Findings: All assessments in volume II are in some way related to management of national forest giant sequoia groves, some more so than others. Several of the assessment reports are directly referred to in this report and are listed alphabetically in this annotated review by author(s).

- University of California, Centers for Water and Wildland Resources. 1996d. **Sierra Nevada ecosystem project, final report to Congress, vol. III, supplemental.** Davis, CA: University of California, Centers for Water and Wildland Resources.
Content: This volume includes late submissions of peer-reviewed papers from volume II, additional commissioned reports, and summary listings of workshops and participants.
Applicable to: All identified ecosystem elements important to the management of giant sequoia groves and surrounding areas.
Critical Findings: Refer to the report.
- University of California, Centers for Water and Wildland Resources. 1996e. **Sierra Nevada Ecosystem Project, final report to Congress, Addendum**. Davis, CA: University of California, Centers for Water and Wildland Resources.
Content: The Addendum, which completes the SNEP Final Report to Congress, features six chapters on an integrated set of reports that lay the framework for simulating alternative late successional conservation strategies and forest management policies in the Sierra Nevada, and two chapters on cases studies on two of the more important symbols of the range - Lake Tahoe and giant sequoia.
Applicable to: All identified ecosystem elements important to the management of giant sequoia groves and surrounding areas.
Critical Findings: The Addendum contains an assessment report on giant sequoia (277-322) also quoted in this Annotated Bibliography as Elliott-Fisk et al. (1996).
- University of California, Centers for Water and Wildland Resources. 1996f. **Sierra Nevada Ecosystem Project, final report to Congress, complete bibliography of SNEP MSA/GS group**.
Content: A bibliography on giant sequoia prepared for the SNEP project.
Applicable to: All ecosystem elements.
Critical Findings: Refer to SNEP Report.
- USDA Forest Service. 1980. **McKinley Grove Compartment Environmental Assessment**. Sierra National Forest, Clovis, CA.
Content: A NEPA document supporting the Decision Notice to permit selection harvest of whitewoods and prescribed burning in the McKinley Grove subwatershed basin.
Applicable to: Vegetation mosaic reference variability
Critical Findings: The environmental assessment contains the following information on: 1) a map of the McKinley Grove subwatershed basin; 2) a map prepared by R.E. Johnson depicting the location of all giant sequoia trees larger than 6 inches DBH; 3) a discussion of the resource attributes; 4) an acreage

estimate of vegetative stratum aggregations; an estimate (i.e., trees per acre and basal area per acre) of species composition; 5) stand exam inventory information; 6) a discussion of alternatives considered and their associated impacts.

- USDA Forest Service. 1988. **Sequoia National Forest land and resource management plan**. Administrative report. Porterville, CA.
  Content: A Land Management Plan (LMP) and associated Environmental Impact Statement (EIS) as required by the 1976 National Forest Management Act.
  Applicable to: All aspects of ecosystem management.
  Critical Findings: Refer to the LMP and EIS reports.
- USDA Forest Service. 1990. **Sequoia National Forest Mediated Settlement Agreement**. Unpublished administrative document, Porterville, CA.
  Content: An arbitrated agreement between the USDA Forest Service and various entities regarding various facets of management activities in the Sequoia National Forest.
  Applicable to: All aspects of ecosystem management.
  Critical Findings: Refer to the mediated settlement agreement.
- USDA Forest Service. 1993. **California spotted owl Sierran Province interim guidelines environmental assessment**. Pacific Southwest region, San Francisco, CA.
  Content: A NEPA Environmental Assessment documenting the environmental analysis process to select an interim short-term strategy to manage habitat for spotted owl on national forests in accordance with the requirements of the National Forest Management Act. (NFMA).
  Applicable to: All ecosystem elements with particular focus on the fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: Three alternatives were evaluated: alternative 1-no action; alternative 2-technical team recommendations; and alternative 3-cumulative effects analysis (CEA) process. Alternative 2 was selected as the preferred alternative. Specific guidelines on stand conditions, snag retention, and fuel loading are listed.
- USDA Forest Service. 1996. **Grant sequoia memorandum of understanding (MOU) for the giant sequoia ecology cooperative**. Copies of the MOU agreement can be obtained from the USDA Forest Service, Sequoia National Forest, 900 West Grand Avenue, Porterville, CA.
  Content: Agreement on leadership in applied research on the ecology of grant sequoia-mixed conifer forests.
  Applicable to: All aspects of ecosystem management.
  Critical Findings: Refer to the MOU agreement.
- USDI Bureau of Land Management. 1995. **Riparian area management**. Technical Reference TR 1737-9 1993. BLM Service Center, P.O. Box 25047, Denver, CO 80225-0047.
  Content: A process for assessing whether a riparian-wetland area is functioning properly.
  Applicable to: Water ecosystem element.

Critical Findings: Refer to the report.

- van Wagtendonk, J.W. 1985. **Fire suppression effects on fuels and succession in short-fire-interval wilderness ecosystems**. In: J.E. Lotan, B.M. Kilgore, W.C. Fischer, and R.W. Mutch, editors. Proceedings of the symposium and workshop on wilderness fire. Gen. Tech. Rep. INT-182. Forest Service, U.S. Department of Agriculture; 119-126.
  Content: A study on the effects of fire suppression on fuels and succession.
  Applicable to: Organic debris and fire ecosystem elements.
  Critical Findings: Refer to paper.
- Verner, Jared. 1998. **Personal Communication**.
  Content: Discussion with Bob Rogers on snags in mixed conifer giant sequoia groves (November 6, 1998).
  Applicable to: Organic debris ecosystem element and snag density indicator.
  Critical Findings: Refer to text of this report.
- Verner, J.; Boss, A.S. 1980. **California wildlife and their habitats: western Sierra Nevada**. Gen. Tech. Rep. PSW-37. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 439 p.
  Content: California wildlife habitat relationships are examined.
  Applicable to: Wildlife and vegetation mosaic ecosystem elements.
  Critical Findings: A system to provide land managers with quantitative information on the responses of wildlife species to the land management activities is described for four zones in California. Refer to the report for detailed information.
- USDA Forest Service. 1992. **The California spotted owl: a technical assessment of its current status**. In: Verner, J.; McKelvey, K.S.; Noon, B.R.; Gutierrez, R.J.; Gould Jr., I.; Beck, T.W., technical coordinators. Gen. Tech. Rep. PSW-GTR-133. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture.
  Content: An assessment of the current status of the California spotted owl, its biology and habitat use, and forests where the subspecies occurs in the Sierra Nevada and southern California. The report suggests the direction of future inventories and research, identifies projected trends in the habitat, and offers guidelines and recommendations for management of California spotted owl.
  Applicable to: All aspects of ecosystem management.
  Critical Findings: Refer to the report.
- Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, D.D. 1985. **Management of giant sequoia**. In: Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, Douglas D., technical coordinators. Proceedings of the workshop on management of giant sequoia; 1985 May 24-25; Reedley, CA. Gen. Tech. Rep. PSW-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, U.S. Department of Agriculture; 47 p.
  Content: Proceedings of the first workshop on management of giant sequoia.
  Applicable to: All aspects of ecosystem management of giant sequoia groves.
  Critical Findings: Refer to the Proceedings.

•Weatherspoon, C. Phillip. 1990. ***Sequoiadendron giganteum* (Lindl.) Buchholz Giant Sequoia. In Silvics of North America**. Volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture; 552-562.
Content: A report on the silvical and ecological characteristics of giant sequoia.
Applicable to: Primarily the fire, organic debris and vegetation mosaic ecosystem elements.
Critical Findings: A general description is provided on the native range, climate, soils and topography, associated forest cover, life history, rooting habit, reaction to competition, damaging agents, special uses and genetics of giant sequoia

•Weatherspoon, C. Phillip. 1996. **Fire-silviculture relationships in Sierra forests**. In: Sierra Nevada Ecosystem Project: final report to Congress, vol. II, chap. 44. Davis, CA: University of California, Centers for Water and Wildland Resources.
Content: A brief overview of the relationship of silviculture and fire management.
Applicable to: Fire severity, fire return rate, weight of down material, snag density, patch and gap frequency, plant community
Critical Findings: Gaining an understanding of the relationship of the disciplines of silviculture and fire management can contribute to more intelligent ecosystem management. Additional research is needed to clarify basic relationships between fire regimes and the dynamics of stands and landscapes. Adaptive management experiments (e.g., Kings River Administrative Study) testing a range of silvicultural and fire treatments should be undertaken.

•Weatherspoon, C. Phillip; Skinner, C.N. 1996. **Landscape-level strategies for forest fuel management**. In: Sierra Nevada Ecosystem Project: final report to Congress, vol. II, chap. 56. Davis, CA: University of California, Centers for Water and Wildland Resources.
Content: This paper reviews past and current approaches to managing fuels on a landscape basis and proposes an outline for a potential fuel-management strategy for Sierra Nevada forests.
Applicable to: Fire severity, fire return rate, weight of down material, patch and gap frequency, plant community.
Critical Findings: The authors conclude that: "High severity wildfires are considered by many to be the greatest single threat to the integrity and sustainability of Sierra Nevada forests. The continuing accumulation of large quantities of forest biomass that fuel wildfires points to a need to develop landscape-level strategies for managing fuels to reduce the area and average size burned by severe fires. Concurrently, more of the ecosystem functions of natural fire regimes-characterized in most areas by frequent low-to moderate-severity fires--need to be restored to Sierran forests."

•Weiss D.R.; Gelobter, A.; Haase, S.M.; Sackett, S.S. 1997. **Photo series for quantifying fuels and assessing risk in giant sequoia groves**. Gen. Tech. Rep. PSW-GTR-163. Forest Service, U.S. Department of Agriculture; 49 p.

Content: A photo series is provided which provides a rough estimate of the amount of fuel for giant sequoia groves.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: A visual inventory of downed woody fuels using a photo series can be made for giant sequoia groves. The fuel information in the photo series can in turn be used to predict fire behavior. A table containing rate of spread and fireline intensity predictions for a single set of environmental conditions is included in the photo series.

• Wemple, B.C.; Jones, J.A.; Grant, G.E. 1996. **Channel network extension by logging roads in two basins, western Cascades, Oregon**. Water Resources Bulletin 32(6): 1195-1207.
Content: Assessment of hydrologic integration of an extensive logging-road network with stream network in two adjacent 62 and 119 square kilometer basins in western Cascade, Oregon.
Applicable to: Stream channel morphology, sediment, and water ecosystem elements.
Critical Findings: 1) 57 percent of the surveyed road length connected to stream network via a variety of engineered features (e.g., road ditches); 2) enhanced routing efficiency (indexed as increase in drainage density) due to connected road segments provides explanatory mechanism for changes in hydrograph shape following road construction; 3) timing of road development and accompanying hydrologic integration of the road network corresponds to the timing of observed changes in peak flows of Lookout Creek and Blue river.

• Western Timber Service, Inc. 1970. **Sequoia tree inventory**. Western Timber Service, Inc., Arcata, CA. An unpublished report to the National Park Service, Sequoia and Kings Canyon National Parks, Three Rivers, CA. Content: a 100 percent inventory of giant sequoia trees conducted between 1964 and 1976 in Sequoia and Kings Canyon National Parks.
Applicable to: Vegetation mosaic, fire and organic debris ecosystem elements.
Critical Findings: A 160,911 giant sequoia trees in 35 giant sequoia groves were inventoried. This data base is the basis for the research papers by Stohlgren (1991, 1992, 1993a, 1993b).

• White, P.S.; Pickett, S.T.A. 1985. **Natural disturbance and patch dynamics: an introduction**. In: The ecology of natural disturbance and patch dynamics (S.T.A. Pickett and P.S. White, eds.). San Diego, CA: Academic Press; 3-13.
Content: A reference on natural disturbance and patch dynamics.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: A patch is defined as the resultant unit of vegetation arising within a gap. Refer to the paper for further information.

• Whitmore, T.C. 1989. **Canopy gaps and the two major groups of forest trees**. Ecology 70: 536-538.
Content: A paper on canopy gaps.
Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
Critical Findings: Pioneer plant species usually have numerous lightweight, well dispersed seeds that are incapable of germinating or becoming established in shade, and tend to have rapid height growth. A climax species tend to have

fewer larger seeds which are capable of germinating and becoming established in shade. Refer to the paper for further information.

- Willard, Dwight. 1995. **Giant sequoia groves of the Sierra Nevada, a reference guide**. Self published. Address inquiries to D. Willard, P.O. Box 7304, Berkeley, CA 94707.
  Content: A self published reference guide on all known giant sequoia groves.
  Applicable to: All ecosystem elements.
  Critical Findings: Information is provided in this reference guide on: introductory overview on giant sequoia; groves north of the Kings River, southern Kings River groves: Kaweah River watershed groves; Tule River groves: other southern groves; selected notes on timber volume and forest structure based on historical cruise information.
- Worrall J.J.; Correll, J.C.; McCain, A.H. 1986. **Pathogenicity and teleomorph-anamorph connection of *Botryosphaeria dothidea* on *Sequoiadendron giganteum* and *Sequoia sempervirens*.** Plant Disease 70(8): 757-759.
  Content: A pathogenicity study of *Botryosphaeria dothidea* on giant sequoia and coast redwood.
  Applicable to: Fire, organic debris, and vegetation mosaic ecosystem elements.
  Critical Findings: Pathogenicity of *Botryosphaeria dothidea* to giant sequoia and coast redwood was demonstrated. The organism causes twig and branch dieback on giant sequoia and bole damage in coast redwood. Top killing was occasionally seen in both hosts. Wounding and/or weakened/dead bark of giant sequoia and coast redwood is necessary for infection by *Botryosphaeria dothidea*.
- Zinke, P.J.; Crocker, R.L. 1962. **The influence of giant sequoia on soil properties.** Forest Science 8(1): 2-11.
  Content: The properties of soils under old *Sequoia gigantea* trees (1500 years and older) at three locations in the Sierra Nevada of California were evaluated.
  Applicable to: Vegetation mosaic, fire, and organic debris ecosystem elements.
  Critical Findings: Soil properties (i.e., bulk density, weight of roots, moisture equivalents, carbon content, nitrogen content, and contents of individual exchangeable metallic cations (Ca^{++}, Mg^{++}, K^{+}, and Na^{+}) varies laterally from the tree trunk out depending on whether bark humus or leaf humus predominated on the soil. Analyses of bark and leaf humus indicated corresponding differences in content of respective elements.
- Zinke, P.J.; Stangenberger, A.G. 1994. **Soil and nutrient aspects of *Sequoiadendron giganteum*.** In: Aune, Phillip S., technical coordinator. Proceedings of the symposium on giant sequoias: their place in the ecosystem and society; 1992 June 23-25; Visalia, CA. Gen. Tech. Rep. PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 69-77.
  Content: Soil-related reasons for the present limited range of giant sequoia and the effects of long-lived trees on soil are evaluated and discussed in this paper.
  Applicable to: All ecosystem elements with a focus on the vegetation mosaic and organic debris ecosystem elements.

Critical Findings: "The estimation of weight and elemental composition of a recently fallen giant sequoia tree indicates that only one ton of the total of nearly 200 tons of weight is derived from the soil. These are essential mineral elements, however, allowing survival of the tree. The long-lived tree, on this soil for more than a thousand years, has maintained a soil with high base status due mainly to high exchangeable calcium, a high pH, and a high organic matter content. This is in contrast to base-depleted acid soils developed under associated mature conifer tree...The optimum soil for the survival of giant sequoia from seedling to mature tree is a soil with development not too weathered nor excessively young and stony; a soil that is well-drained or moisture; and a soil high in organic matter recharged with basic elements in bigtree litter."

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Developing and executing effective ecosystem management plans for giant sequoia groves requires input and work from a large number of concerned individuals. There are people like Dr. Nate Stephenson, Dr. Tom Bonnicksen, and many others

too numerous to list here who have an "active" interest in giant sequoia management. Working together we can make a difference.

GLOSSARY

adaptive management - Implementing policy decisions as an ongoing process that involves monitoring results. It applies scientific principles and methods to monitor, then incrementally improve, resource management as managers and scientists learn from experience and from new scientific findings. Adaptation is also made as social changes and demands warrant.

aggregation - unit of vegetation that is homogenous in one or more attributes.

CASPO - California Spotted Owl guidelines

canopy (forest) - The more or less continuous cover of leaves and branches formed by the crowns of adjacent trees or shrubs.

cohort - each aggregation of trees that starts as a result of a single disturbance (Smith 1997).

component (ecosystem) - Refer to **elements**

desired condition - Land or resource conditions which are expected to result if planning goals and objectives are fully achieved.

ecosystem - A system formed by the interaction of living organism (including people) with their environment. Spatially, ecosystems are described for areas in which it is meaningful to talk about these relationships.

elements (of an ecosystem) - The basic building blocks of ecosystems. There are three fundamental types of elements: **components** are the kinds and numbers of organisms and physical objects that make up the ecosystem -- the "pieces"; **structures** are the spatial distribution or patterns formed by these "pieces", and **processes** are the flow or cycling of energy, materials, and nutrients through space and time.

environmental indicator - A quantitative measure of an ecosystem element which is used to describe the condition or an ecosystem. Environmental indicators are affected by management and change over relatively short periods of time.

gap - a site at which a canopy individual or individuals have died resulting in a change in the surviving community (Christensen and Franklin 1987).

goals (national forest giant sequoia management) - The Mediated Settlement Agreement (MSA, 1990) mandates that: "The goal...shall be to protect, preserve, and restore the groves...for the benefit and enjoyment of future generations." Although the terms are left undefined in the MSA document, the intent appears to be:

•protect naturally occurring groves from events that are contrary to, or disruptive of, natural ecological processes. Protect historical, prehistorical, and biological artifacts within the groves from agents that could destroy them or accelerate their natural rate of deterioration.

•preserve the groves by allowing ecological processes, or equivalents thereof, to maintain the dynamics of forest structure and function.

•restore the groves to their natural state where contemporary human activities have interfered with the natural process--especially the processes of fire and hydrology.

landscape - An area of interacting ecosystems where patterns are repeated because of geology, landform, soils, climate, biota, and human influences.

monarch (giant sequoia) - A large and old (relative to the species) giant sequoia tree.

natural state (of giant sequoia groves) - A range of probable conditions that occurred during the adaptation of the giant sequoias to their environment.

NEPA - National Environmental Policy Act of 1969. The Act declares it a national policy to encourage productive and enjoyable harmony between people and their environment. A detailed Environmental Impact Statement (EIS) is required for all "major federal actions significantly affecting the quality of the human environment."

NFMA - National Forest Management Act of 1976.

patch - The resultant unit of vegetation arising within a gap (White and Pickett 1988).

presettlement times – Prior to 1850 and in the context of this paper, after 1000.

process (ecosystem) - Refer to **elements**

RPA - Resources Planning Act of 1974.

recommended management variability - A subset of reference variability; defines conditions that may omit extremes that would prejudice the attainment of desired conditions.

reference variability - The distribution of data values for an environmental indicator over a selected period of time. Also known as natural range of variability, range of variability, historic range of variability.

resilience - The ability of an ecosystem to maintain diversity, integrity, and ecological process following disturbance.

scale - The degree of resolution used in observing and measuring ecosystem processes, structures, and changes over space and time.

seral - The identifiable stages in development of a sere, from an early pioneer stage, through various early and mid-seral stages, to late seral, subclimax, and climax stages. The stages are identified by different plant associations (different species composition and/or community structure), different ages of dominant vegetation (usually related to differences in structure), and by different microclimatic, soil, and forest conditions (Kimmins 1997).

sere - The sequence of biotic communities and associated nonliving environmental conditions that successively replace each other on a given area of land, from the time of a disturbance that has removed or disturbed the previous community and nonliving conditions, to a final, relatively stable and self-replacing community (the climax). The sere is divided into a series of seral stages (Kimmins 1997).

structure (ecosystem) - Refer to **elements**

succession - The predictable, orderly, long-term developmental changes of an ecosystem that involve changes in species composition, structure, and community processes.

sustainability - the ability of an ecosystem to maintain diversity, productivity, resilience to stress, health, and yields of desired values, resource uses, products or services over time while maintaining its integrity.

ENDNOTES

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[2] Mr. Rogers is the Giant Sequoia Specialist for the USDA Forest Service, Sequoia National Forest, 900 West Grand Avenue, Porterville, California 93257

[3] The common name, giant sequoia, and the scientific name, *Sequoia gigantea* (Lindl.) Decne., rather than *Sequoiadendron giganteum* (Lindl.) Buchholz, will be used in this paper. Justification for this is documented in Davidson (1972) and Piirto (1977).

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